

BELOW-GROUND INTERACTIONS AT THE TREE-CROP INTERFACE IN THE
HIGHLANDS OF KENYA

By

MUTHIRI DOBHOJIAJIAN

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To my parents and Kevin Wilson

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**BELLOW-GROUND INTERACTIONS AT THE TREE-CANOPY INTERFACE IN THE
HIGHLANDS OF KENYA**

By

Mathias Gerschlager

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Chairman: Dr. F. E. Benschawinkel-Wier

Major Department: School of Forest Resources and Conservation

Competition for growth resources between woody and nonwoody (craep) species is said to be the main cause for craep-fallure in *hedgepole* (intercropping) (shytopping) in the humid tropics. However, the mechanisms of such interspecific competition have not been clearly understood. Results of a series of investigations on these aspects, conducted in the highlands of Kenya, are reported here.

In the first experiment, soil-water changes and root dynamics in a *hedgepole* (*Cassia siamea* (Lam. de Wit.)) and *maize* (*Zea mays* L.) intercropping system were monitored. Soil-water content decreased more rapidly and root root density of *hedgepole* and *maize* (expressed as root length $\text{cm}^2 \text{ soil}^{-1}$) increased under the *hedgepole* intercropping system compared to the sole crop system. Furthermore, the

intercropped maize and higher root density than sole-cropped maize (i.e., when maize was grown alone). Harvest contribution through root turnover of the woody species in a cropping system of about 120 days was estimated as 7 kg N and 0.2 kg P ha⁻¹.

The influence of pruning the above-ground biomass of the woody species on the extent of water availability in the system was assessed in another study. Soil water availability was higher under the periodically-pruned hedgerows than under the unpruned ones. Maize produced more roots when grown under unpruned maize than with hedgerows or in a sole-crop. A third study showed that above-ground pruning of *Acacia* reduced the number and distribution of its structural roots, however, when the root system was modified artificially by planting a galvanised-iron sheet barrier around the tree up to 100 cm root depth, the number and distribution of structural roots increased.

In summary, when grown with a woody component, maize produced more roots than under sole-cropping condition and root production was high when soil water availability was low. Soil water was depleted more rapidly under hedgerows intercropping than under maize-sole-cropping condition. Above-ground pruning seemed to influence the structural root (>2 mm in diameter) distribution of the woody species, but an effect on fine-root (<2 mm in diameter) density was not clear since root density was also influenced by soil water status. Future research should focus on the effect of time and frequency of pruning the woody species on its root dynamics and influence on growth of alleycrops.

CHAPTER I INTRODUCTION

Hedge-row intercropping (commonly called alleycropping) was developed as a low input technology in the tropics to overcome soil fertility depletion and facilitate continuous cropping in areas where the traditional bush fallow system did not sustain crop yield and soil fertility. The system involves growing of annual food crops (alleycrops) in the alleys, between frequently-planted hedgerows of woody species (Kang et al., 1990). The greenings are incorporated into the soil either as green manure or are spread on the surface to provide additional benefits such as soil and water conservation (Tong, 1993; Nair et al., 1994). The technology, originally developed for humid and subhumid tropics, has also been tried in arid/semi-arid tropics, but with little success (Singh et al., 1990; Rao et al., 1991; Juma, 1993). Although most of these reported failures were attributed to below-ground interactions, especially competition for water, between the hedgerow and crop species, adequate research has not been conducted to understand the mechanisms of below-ground interactions between the hedgerow and crop species, and how such interactions affects the performance of the system.

Several factors are important in the study of below-ground interactions. Some of these are root dynamics and characteristics of the interacting species, impact of

above-ground management such as pruning and root dynamics, and what value under increasing root systems, the mutual-effects of water stress and root dynamics on each another, and species-differences among commonly-used hedgerow species. The dissertation collects the results of a set of studies on these aspects conducted in the semiarid and irrigated highlands of Kenya. The field investigations, focused on the root-rhizome interface (which, as used in this dissertation, refers to the area in which the woody and herbaceous species interact for the growth resources such as soil water, nutrients, and light), were carried out during September 1990 to August 1991.

The dissertation has seven chapters. Following the brief introduction, Chapter 2 presents the current state of knowledge on below ground interactions in agroforestry systems. Chapter 3 reports the results of an investigation on soil water, root dynamics, and crop performance in a hedgerow-intercropping system. Studies on the above- and below ground competition at the root-rhizome interface are reported in Chapter 4. Chapter 5 reports a characterization of root systems of four-year-old *Acacia* trees; it is followed by Chapter 6 which gives a synthesis of results, summary, and conclusions. Finally, in Appendix I, root-density comparisons between two commonly used hedgerow species (*Quercus* and *Calliandra*) is explained.

CHAPTER 2 BELLOW-GROUND INTERACTIONS IN AGROFORESTRY: THE PRESENT STATE OF KNOWLEDGE

Organized international efforts in agroforestry started just under two decades ago. Reviewing the "history" of developments in agroforestry research during this period, Hall (1983) grouped the major areas of effort into three categories: methodological studies, system- and component-definitions, and experimental and quantitative investigations. Although both biophysical and socioeconomic aspects have been addressed under all three categories, a vast majority have been of biological nature. Lately, experimental and quantitative studies on biological aspects (such as screening and selection of multipurpose trees, components, and system management trials, and prototype-technology evaluations) have become the dominant area of agroforestry research (Hall, 1983). Yet, studies on interactions between the woody and nonwoody components of agroforestry systems have been relatively scanty although it has often been emphasized in the growing body of agroforestry literature that the success of agroforestry relies heavily on exploiting such component interactions (Hall, 1983; Hall, 1984; Sanchez, 1985).

Whichever investigations that have been made in agroforestry interaction studies have followed the path of systematic unearthing, studies which have mostly followed the sensitive ecological studies on interactions. However, most reports on

this subject is agroforestry literature not of broad scope, reporting only the net effects—that are, change into specific—on productivity especially of the nonwoody components (Rice et al. , 1984). The mechanisms involved have not been a major focus of these studies although several researchers have explored the issue (Tilman, 1986; Anderson and Sinclair, 1983; Rice and Macklin, 1981). Thus, knowledge on this subject is relatively shallow, and a review of the subject will inevitably be brief especially if it is based on (broadly) agroforestry literature. Therefore, relevant information will also be drawn from the extant literature on tree-based systems in the tropics as well as those in the temperate zone. First of all, it is important to clarify the concepts of some terms used in this dissertation.

Explanation of Some Terms and Concepts

In the context of this discussion, the word *interaction* refers to the influence of one species or component of the system on the performance of other component(s), and that of the overall system (Rice et al. , 1984). The nature of interactions in agroforestry systems can be measured in various ways. Agroforestry researchers generally seem to use the terms "below ground" and "above-ground" as adjectives to describe interactions (mainly negatively) between components for growth factors absorbed through roots (nutrients and water) and those distributed/interrupted through leaves (mainly nutrient energy) (Singh et al. , 1981; Macklin et al. , 1981; Anderson and Sinclair, 1983; Ogil and Black, 1984). Partitioning the interactions into above- and below-ground groups provides a sound basis for studying the processes involved as well

as suggesting improved management options for components and systems. However, the processes are interdependent and their net effects can be positive (beneficial or production-enhancing) or negative (harmful or production-decreasing) (Oser and Mosher, 1993). These effects can be direct or indirect. For example, for herbaceous components of agroforestry systems, direct effects may result from the microclimate modification or changes in nutrient relations caused by physical presence of the woody component in the system, and indirect effects may result from management practices associated with or necessitated by the presence of woody components.

Another way of examining the nature of interactions is based on the arrangement of components in time and space. For example, the nature of interactions could be different in agroforestry systems where the component associations are sequential (e.g., time-dominant, e.g., tree fallows), simultaneous (e.g., space-dominant, e.g., silvopasture, boundary planting), or a combination of simultaneous and sequential (e.g., shaded perennial-crop systems, mangro, rotational hedgerow intercropping).

Yet another perception of interactions in agroforestry systems is the complex set of economic and social interactions in the context of farmer and community, and these interactions are as important as biological interactions. Nevertheless, the focus here is on biological interactions, especially the below ground interactions.

Another term that, though commonly used, does not seem to have been well understood in such discussions, is "tree/crop interface." From the early stages of agroforestry research, it was recognized that agroforestry experimentation was more

complex than that of single-species stands because of the presence of a tree component that occupies a large and volatile portion annual food crop yield (Hushey et al., 1988). In order to derive an optimum spacing between the tree and crop, an understanding of the processes (just as west as north as south) and spatial arrangement of the tree species was considered to be very important (Hushey et al., 1988). Therefore, studies were conducted with a single row of trees at the center of an experimental plot and food crops grown on either side of the tree row. In each plot, the zone in which the tree and crop species interacted for light interception, nutrient- and water uptake was referred to as *Tree/Crop Interaction* (Hushey et al., 1988). This is the concept of *canopy interface* as used in this dissertation. It needs to be clarified that the term “canopy interface” applies not only to monospecific plots, but also to alleycropping system in which multiple rows of tree species exist at varying inter-row spacings.

Indicators of Interactions

As mentioned earlier, the results of interaction are commonly expressed in terms of the net effect on yield of biomass or of some (selected) economic products. While this may appear to be useful in a practical sense, it does not give any indication of the mechanisms involved, and therefore, are not useful for manipulating the conditions for better results. It is imperative that interaction studies be more analytical.

Under conditions of resource inputs, the most common form of interaction in agroforestry systems is likely to be competition between the woody and nonwoody

competition (Jongst et al., 1994; Nier et al., 1994). It is therefore not surprising that most intercropping studies deal with competition. Since competition for soil water (strong)over the competition for term "soil water" refers to both soil water and soil moisture, these latter terms often are used interchangeably in the literature) is the most important form of competition in wetland conditions (Jongst et al., 1994; HCB&F, 1995), and because water uptake will be determined by the extent of root proliferation, the study of root system dynamics is crucial to the study of competitive interactions in wetland conditions.

Methods of Root Analysis

The extent of root proliferation in a soil is dependent on various ways (de Willigen and Van Mesterhuyk, 1987; Van Mesterhuyk and Bruijnzeel, 1992). The most common among these are

- 1) Root length density—the length of roots present in a unit volume of soil and it is expressed as cm cm^{-3}
- 2) Root biomass—the dry weight of roots present in a unit volume of soil and it is expressed as g cm^{-3}
- 3) Root surface area—the surface area of roots in a unit volume of soil and it is expressed as $\text{cm}^2 \text{ cm}^{-3}$
- 4) Root spread—the number of root tips (>1 mm in diameter) observed in a unit area of the observation plane

- 2) Root structure—vertical and horizontal arrangement of the roots (more > 2 mm in diameter)

Among these terminologies, root length density (root density) is widely used as an index to express the magnitude of competition, nutrient and water uptake. Therefore, given the focus of the dissertation on below ground interactions, the same terminology is used in this dissertation. Several methods are available to measure root density, each has some advantages and disadvantages (Julian, 1975; Magill et al., 1992; Taylor et al., 1992). The most commonly used methods are:

- 1) Excavation (Sampling) method—root observations are made by mapping the outcropping roots at an observation plane (Rice et al., 1992). This method requires large amount of soil excavation to expose an observation plane. Therefore, this method involves an enormous amount of labor and time, and the loss of fine roots for an observation is very high. Moreover, multiple samplings are not possible.
- 2) Minirhiz method—root samples are collected by driving a metal block of diameter 1 cm into the soil (Johnson and Allmaras, 1985). This method allows multiple sampling. Determination of root length density through the minirhiz method, although the variability is low, is very expensive and time consuming since many excavations are needed to remove the metal block from the soil. This method needs less time and labor compared to the excavation method.
- 3) Root observation through transparent root growth and death can be visually observed by inserting a glass tube into the soil (Klopfer and Koppa, 1996).

Observations can be made using a camera over a sensor which is important to study the root turnover. However, it is not possible to quantify the root turnover, root turnover can be defined as the amount of roots died, because of age and/or stress, during a given time. Moreover, this method requires expensive equipment to construct the root system. Another drawback of this method is its suitability for seasonal, randomization after installation of the tubes.

- 4) Coreg method: root samples are collected by inserting a tube of desirable diameter into the soil (Van Noordwijk, 1994). In contrast to the above methods, root density determination through coring, is relatively inexpensive and can be carried out in shorter time. In addition, random samples can be taken through coring to maintain the variability. Through coring, it is possible to collect hundreds of samples, provided adequate labor is available. However, as with all root sampling methods, the precision of the coring method in estimating root biomass production and root length density has not been clearly understood. Given the need of multiple and inexpensive sampling, the coring method was used in this study.

Advantages of Nitrogen-Greenhouse Experiment in Multigrow Technology

The suggested evaluation of beneficial interactions resulting from the inclusion of a tree-component in annual cropping systems are: (i) deeply penetrating tree roots capture the soil nutrients from deeper layers and recycle them in the soil surface for use by annual crops (Mia et al., 1994), (2) incorporation of tree prunings into soil adds

organic matter and nutrients (Goldman 1994, Iqbal, 1997), (3) leguminous nitrogen-fixing trees add atmospheric nitrogen into the system through biological nitrogen fixation (Shaverdon, 1997), (4) trees mobilize the unavailable nutrients, particularly phosphorus, into available forms through mycorrhizal activity (Malt et al., 1994), and, (5) addition of organic matter improves soil physical properties and soil water status (Lai, 1993). The extent of reduction of the combined benefits of these factors manifested as soil fertility improvement was widely tested at Indragiri Intercropping Technology in the humid and subhumid tropics. In general, soil fertility and crop yields were found to be higher under legume intercropping compared to continuous sole cropping of annual crops in both dry, Aflak, and Uluhehi, and Uluhehi under conditions of both no or no water stress (Kang et al., 1990, Tansuh and Darling, 1990, Roseman et al., 1992).

Following these positive results in the humid and subhumid tropics, the technology was tested in the arid/semi arid tropics. But studies have given mixed results. In the arid/semi arid tropics, annual sole crop systems where only a small part of the rainfall, much of the water is left either deep in the soil or is lost through evaporation (Rao et al., 1991) (ICRAF, 1995). It has been hypothesized that alleycropping has the potential to extend the cropping period under such conditions through water conservation (Joshi et al., 1988). For example, application of legume greenman as mulch in the alleys may improve soil water retention through reduction of evaporation, which would allow the cultivation of a high-yielding long-duration crop or an additional short-duration crop in the place of a low-yielding short-duration crop. However, the ground materials

are often removed from the field for other uses such as animal fodder (Coffman et al., 1989). Even if they are not removed, the quantities of mulch produced are relatively low and the competition for water between the hedge and crop could be so high that the potential advantages of mulching are seldom realized under practical situations. As the water loss continues both from the soil and foliage of hedges and alley crop species, competition for water between tree and crop components may increase. Under conditions of severe water stress, the hedge species could out-compete the alley crop and seriously affect the growth and productivity of the latter.

Although the presence of extensive roots of woody species in the alleys under below-ground competition for water uptake have been demonstrated (Singh et al., 1985; Sadehna et al., 1994), the factors that lead to competition have not been adequately explored. According to Singh et al. (1986), higher maize yield was obtained from the alley when there was a polyethylene barrier between the hedgerow and the first crop row to restrict root growth of hedge species, compared to the yield of alley crop grown without any barrier. Although the reduced below-ground competition or allelopathy, the mechanisms of yield reduction of alley crop have not been reported, nor the relationship between yield reduction and such parameters as root-length density, root spread and diameter, and soil water content in the alley. Based on the observations of severe yield reduction of maize under hedgerow intercropping compared to sole crop, Singh et al. (1994) suggested that below-ground competition rather than above-ground competition could have more impact on maize yield reduction. Above-ground competition can be controlled to some extent by shoot

growing, but there are no such management options to control below-ground competition. An understanding of the above relationships will enable us to develop appropriate management practices to minimize below-ground competition in allelopathy in the forested region.

Root Characteristics of *Bidigare* Species in *Bidigare* Interspecific

Most tropical trees have extensive root systems (Mishra and Vaa, Manivargh, 1985) and they exploit large soil volume for water and nutrient uptake. Due to their perennial nature, trees have an advantage over annual crops in nutrient and water uptake. This results in competition between woody species and annual crops for growth resources such as water which is particularly limiting in arid/semi arid (Rao et al., 1985). The mechanism of below ground competition via rhizome root dynamics is explained to a limited extent in a study conducted by Jensen et al. (1944) in Tanzania, in which vertical distribution of fine roots of five species was observed. The species were *Acacia* (*Acacia drepanolobium*, *Eucalyptus tereticornis*), *B. conchoides*, *Eucalyptus leucoxylon*, and *Prosopis juliflora*. Root distribution of the species was observed indirectly by sampling 25 cores and calculating fine root biomass. This type of observation was also made by Dhyal et al. (1992) under forest allelopathy conditions in northern India. But, their investigation did not specify the sampling distance from the *Bidigare* and details of above-ground-essential information for explaining the root distribution of the *Bidigare* and the allelopathy species. In Madhuban, Kanya (the main location where the present studies were conducted), *Acacia*

(1995) observed that the root density of the hedge species decreased as the distance from the hedgerow increased. But, these results were not conclusive because the study was confined to the top 40-cm of soil, the number of samples was limited, and there was only a single set of observations. Balingwa et al. (1991) studied the root distribution of *Eucalyptus* (yes), *Acacia* (no), *Mikania cordifolia*, *Senecio jamaica* and *Cordia alliodora* in an arid region. They observed (yes), a single set of observations) root distribution up to 120-cm depth and 300-cm horizontal distance from the hedgerow to 40-cm intervals. Their study showed a high density of roots in the top 30 cm of soil. But, in order to explain the degree of below-ground competition, we need information on how far and how deep the roots are distributed to help estimate appropriate spacing between hedgerows in alleycropping.

One way of reducing below-ground competition could be to space the hedgerows wide apart. For example, Rao et al. (1988) studied the amount of yield reduction of sorghum under different spacings of leucaena hedgerow for four years at a semi-arid tropical location in southern India. They observed higher yield reduction in the closest spaced hedgerows (1-33 m) than in the widest spaced (4-95 m). However, yield of sorghum was lower even in the widest spaced hedgerow than that of sole sorghum. They postulated that below-ground competition could have caused the yield reduction in the alleys. Although they observed root distribution of leucaena in the top 30 cm soil, soil water status in agroforestry and sole crop systems was not studied. Thus, as summarized by Rao et al. (1994), it is clear that there are serious gaps in our

knowledge on the relationship between root characteristics and soil water at various depths and distances from the bole/trunk in the natural tropics.

Root Characteristics as Related to Stock-Pruning of Bole-pruned Species

Above-ground pruning (hereafter referred to as pruning) is a common management practice in many perennial plantations. The term is widely and differently used – in forest and fruit trees, it is used to denote removal of some old branches; and, in agroforestry, it involves complete removal of above-ground vegetation produced after the previous pruning. The objective of pruning, however, is the same in both systems: to maximize the growth and quality of the economic product of the pruned tree. In horticultural crops, pruning is mainly done to maximize the yield and improve the quality of fruits. In forest crops such as grapes (*Vitis rotundifolia*) and coffee (*Coffea arabica*), pruning is an inevitable management practice to stimulate flowering (Phillips, 1978). In forest plantations, however, pruning is done to improve the quality of the timber (Smith, 1994). Several studies have been conducted in both horticultural and forest trees to determine appropriate pruning regimes. Most of them focused on the above-ground growth (i.e., number and length of stems produced after pruning, stem angle, fruit yield, fruit quality, and stem diameter increase) (Jilka, 1986; Sharp and Giegley, 1995). Pruning of woody species as shearing, in the tropics mostly involves complete removal of above-ground growth at specified heights, with the main objective of increasing light interception by the stay crop. Some studies have been conducted to establish the optimum pruning schedule of the beidge (*Desmodium*

et al., 1964 and 1964). Dupont et al. (1944), for example, measured biomass production and nitrogen content of ground materials of *Leucaena leucocephala*, *Gliricidia sepium*, and *Desmodium gangeticum* under different pruning heights and growing intervals at the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria, and recommended an optimum pruning regime for these species. Some studies have also been conducted to understand influence of pruning on carbohydrate in various plant parts (Chai-Monodrye et al., 1976; Thangthaisri and Bhatt, 1977; Haddad et al., 1985; Williams et al., 1993; Saengsri et al., 1994). Most of these studies have demonstrated the carbohydrate depletion from the roots when the above-ground parts were removed. The depleted carbohydrate from roots was used to produce shoots and this depletion continued until the newly produced leaves became photosynthetically active. As a result of successive carbohydrate depletion, roots may die because of lack of energy source to support their growth and development. However, the effect of pruning on below-ground characteristics, especially of changes in root growth of woody perennials and soil micro, which may have a bearing on managing the below-ground competition, has seldom been experimented. Preliminary results of a study of this nature involving five multipurpose trees in the humid lowlands of North Lampung, Indonesia, showed that a lower height of stem pruning led to a larger number of superficial roots of smaller diameter, but had no effect on shoot root ratios or the relative importance of the structural root (Van Marrewijk and Purnomosidlo, 1992).

Under low soil fertility conditions in a temperate climate, Rejman and Grant (1981) recorded high fine-root activity in Douglas fir (*Pseudotsuga menziesii*) with low above-ground canopy, dense fine-roots, which occupied and confined themselves to near the base of the tap root (0 ± 1), where sugar availability is high – are responsible for exploration and absorption of nutrients and water. In contrast, in the subtropical region of Florida, Eason and Duncan (1982) observed reduction in root activity in citrus (*Citrus sinensis*) when branches were partially removed, but these results may not be directly applicable to the temperate. Although Fowett and Anderson (1981) and Hygren and Campos (1983) observed reduction in root biomass as a result of pruning in the temperate, these studies had some limitations too. For example, the study of Fowett and Anderson (1981) was a pot-study (which showed sudden decrease in root biomass soon after stem pruning), and therefore the results may not be directly applicable to field conditions. The results from the study of Hygren and Campos (1983) were confounded with the seasonal factors during the study period. Moreover, in both these studies only the root biomass changes were mentioned which alone are inadequate to explain the extent of competition, root-length, density or root surface area also need to be reported. In summary, the present state of knowledge on the effect of above-ground pruning on root dynamics of landscape species such as allelopathy in the temperate is inconclusive.

Species Comparison

Root system of a species is influenced mainly by its genetic character; in other words, no two species have similar root system (Rashed, 1977). Therefore, to select

the best species, we used to compare several species for the same desired attribute. Magalhães and Pires (1994) compared 48 species to select the best one for its ability to withstand pruning and found *Calliandra calothyrsus* (willowbush) as the most appropriate species for the coastal Atlantic region of Malawi. Dagnon et al. (1994) also selected 10 species in the humid region of Cameroon for their ability to withstand frequent pruning; they found calliandra to be the best in that respect under those conditions as well. Insect alleyspraying studies have so far used *Leucaena leucocephala* as the hedgerow species because of its fast growth and excellent fodder value (Adekunle, 1993; Benoitaker, 1987; Kang et al., 1998; Singh et al., 1989). However, it was found to be more competitive than other multipurpose trees such as *Gliricidia sepium* or *Crotalaria retusa* because of its deep and extensive root distribution (Bao et al., 1990). Calliandra, which has some of the qualities of leucaena (Alleyspraying and Mulongo, 1994) was identified as an alternative species. Although Magalhães and Pires (1994) and Dagnon et al. (1994) identified calliandra as the best species, its competing ability with crops and root distribution when grown in alleyspraying are not known. Is the national bush of Togo calliandra just a good response when it was compared with gliricidia and leucaena (Adenle and Lehmann, 1995)? Thus, our knowledge about species differences is also rather superficial and scanty.

Effect of Ground Biomass Production

The potential of hedgerow alleyspraying to improve crop yields depends on the amount of above- and below ground biomass produced by the trees, the nutrients added

or recycled in the system, the timely transfer of nutrients from live biomass to crops (the level of competition between trees and crops for growth resources, and the extent of soil nutrient depletion). Several long-term intercropping studies have estimated the nutrient input from above-ground biomass (Kang et al., 1980; Bultman, 1988; Handayani et al., 1994). Many studies have also quantified the decomposition of tree residues (Jena, 1953; Madhuprat, 1955) but the amounts of below-ground biomass added and nutrients recycled through root turnover in hedgerow intercropping have not been reported. This issue may also due to spring which is partially controlled, environmental stress such as drought, and management such as shoot pruning (Ding et al., 1992). It is known that most tree species are known to undergo these seasonal changes in their root growth in temperate regions (Kasamatsu and Iwama, 1988), trees in hedgerow intercropping in the tropical dry-also experience similar changes, probably at a greater rate, because of frequent shoot pruning and strong wet and dry periods in the tropics. This type of root turnover could add significant amounts of nutrients from roots to soil involved in their nutrients (Nambiar, 1987). To date no attempt has been made to quantify the amount of nutrients added through root turnover in an agroforestry system such as hedgerow intercropping.

Summary

The abstract points that emerge from the foregoing review are:

- 1) Component interactive studies, especially those dealing with below-ground

interaction, are study therefore, very little is known about mechanisms involved although several hypotheses and postulations have been proposed based on experiments with synchronous root pruning.

- 2) The most common way of expressing the effects of interactions is in terms of yields of biomass or some (other) economic products, but these are inappropriate for mechanistic investigations.
- 3) The most obvious form of below-ground interaction between the woody and herbaceous components is allelopathy where removal of herbaceous is a competition for water. In addition to study the nature and extent of this interaction, it is essential to study root dynamics, especially in relation to management practices such as foliage pruning.
- 4) Root dynamics (of fine roots) < 2 mm in diameter are usually expressed as root length density (length of roots in an unit volume of soil), root biomass (dry weight of roots in an unit volume of soil), root spread (horizontal and vertical distribution of roots, expressed as root number in an unit area), root surface area (surface area of roots in an unit volume of soil), and root structure (number and angle of structural roots of > 2 mm in diameter).
- 5) The most widely used root study methods are trenching, minirhizotrons, and coring. Each has its own advantages and limitations.
- 6) Fertilizer pruning (removal of selected above-ground parts) is a regular practice in the management of a number of economic crops. But the effect of such pruning on the root dynamics of the species has not been adequately

investigated. Therefore, the present state of knowledge on the topic is superficial and inconclusive. Equally unsatisfactory is the situation regarding differences among species as their response to above-ground pruning, and the knowledge base on the extent of root biomass production and nutrient turnover in agroforestry (alleyspruning) systems on the tropics. The issues raised in the foregoing review are summarized in Fig 2.1.



Fig 1: Summary of the reason that need to be addressed in the non-erect relation

CHAPTER 3
SOIL, WATER, ROOT DYNAMICS, AND CROP
YIELDS IN A RIDGE-TOP INTERCROPPING SYSTEM IN
THE SEMI-ARID HIGHLANDS OF KENYA

Introduction

Ridge-top intercropping was developed as an alternative to the traditional bush-fallow rotational system of the tropics. The system involves growing of food crops in the ridges between frequently sown ground (hereafter referred to as growing) tree hedgerows; the hedgerow prunings are incorporated in the soil either as green manure or spread on the surface for soil fertility improvement and/or conservation (Fleury, 1989; Rung et al., 1990; Kar et al., 1995). The system, originally developed for humid and sub-humid tropics, has also been cited in semi-arid tropics, but with little success (Dough et al., 1989; Kar et al., 1991). Although most of the reported failures in the semi-arid tropics were attributed to the below-ground competition for water between the hedgerow and crop species, no clear attempt has been made to understand the mechanisms of competition and the extent of their influence on the potential of the system. It is therefore important to understand the water relations patterns in the hedgerow intercropping system as relates to the root activities of the hedgerow and crop species.

The potential of hedgerow intercropping to improve crop yields depends on the amount of above- and below-ground biomass produced, the quantity of nutrients added or recycled in the system via the biomass, and the extent of competition for growth resources between hedgerows and crops. Some studies have quantified the nutrient input from above-ground biomass (Duguma et al., 1988), and to some extent, the nutrients added through decomposition of tree residues (Joshiwani, 1989), but not the amounts of below-ground biomass and nutrients recycled through root turnover. Study of root dynamics is critical to the understanding of earth biotransformation relations as well as the extent of below-ground competition for growth resources. Tree roots may die due to aging, which is a genetically controlled process, and due to environmental stress (such as water deficit caused by drought) and/or management (such as shoot pruning) (Yagi and Blackfield, 1981). While root tree species are known to undergo three seasonal changes in their root growth in the temperate zone (Kassamouni and Harman, 1980), even in hedgerow intercropping in the temperate region extensive ground root turnover that is older species because of frequent shoot pruning and during wet and dry periods. The present study was conducted with this background to evaluate the potential of hedgerow intercropping, and the pattern of root dynamics under natural conditions. The specific objectives were to: (i) monitor soil water changes and quantify root growth under hedgerow intercropping in comparison with sole maize, (ii) evaluate the effect of pruning the hedgerows on the growth and turnover of their roots, and (iii) compare crop performance in sole and hedgerow intercropping systems.

Materials and Methods

The Site

The study was conducted at the Intakeken Research Station of the International Center for Research in Agriculture (ICRAIP) in Kenya (1° 30'N and 37° 14'E, 1984 m above sea level; annual temperature is 19° C). The station experiences a semi arid rainfall of 760 mm at two distinct crop seasons, the so-called "long" season from March to June (m: 243 mm) and the "short season" from October to January (m: 315 mm). The prefixes "long" and "short" in the seasons refer to the length of the dry period that follows the season. The rain has a 0 to 4% slope from north to south and 3 to 1% from east to west. The soils are Kikuyu-Kisumu soils characterized by clay loam texture with Kaolinite as the dominant clay mineral and good physical conditions (Kilele et al., 1981). The soil depth varied from 0.7 to 1.2 m. Hard nutrient layers or nodules were noted at varying depths below 0.7 m. The soil had close to 1% organic carbon and moderate levels of phosphorus and potassium at the beginning of the study (Table 3-1).

Experimental Design

A hedgerow intercropping experiment was started in November 1989 with *Acacia drepanolobium* (Lam. ex Wt.) as the hedgerow species and maize [*Zea mays* L. (cv. Kaimosi Orange)] as the first crop component. Every year two crops were grown, one each during the long- and short-rainy seasons. The first crop was maize (*Z. mays* L. cv. Kaimosi Orange) and the second was maize. The maize crop during

Table 3.1. Soil characteristics of the experimental area

Characteristic	Depth (cm)	
	0-10	10-20
Mechanical analysis (%)		
Sand	9	11
Silt	60	58
Clay	31	31
Bulk density ($Mg\ m^{-3}$)	1.56	1.40
pH	6.1	6.0
Organic carbon (%)	0.88	0.78
Extractable P ($mg\ P\ kg^{-1}$)	6.6	4.6
Total cations ($mmol\ kg^{-1}$)		
Ca	3.3	3.3
Mg	1.3	1.4
K	0.6	0.5

the long run of HHS had failed because of very low rainfall. The study reported here was undertaken during October 1993 to July 1994. The experiment had three treatments, replicated three in a randomized complete block design. The treatments considered for this study were: (i) sole maize (maize only) grown without any herbicide inputs (SC+P), (ii) hedgerow intercropping where the pruned materials of hedgerows were put back to the soil as green manure or mulch (HE+GM), and (iii) sole maize (maize only) grown with the recommended rate of fertilizer at 40 kg N and 18 kg P ha⁻¹ (SC+F). The intercropping plots were 16.2 m wide and 30 m long with four hedgerows of *Leucaena* planted along the contour at 5.4 m between rows and 0.4 m within rows. The sole maize plots varied from 200 to 500 m². Trenches, 0.3 m wide and 1 m deep, were dug at the beginning of each season 2.7 m away from border hedgerows of the intercropping plots to grow *Leucaena* roots and eliminate the possible interference of tree roots with the adjacent sole maize plots.

The hedgerows were pruned twice in each rainy season, once at the beginning of the season and the next during the middle of the cropping season. The first pruned material in HE+GM was incorporated in the soil by plowing during land preparation and the second pruned material was spread as mulch between maize rows. *Leucaena* pruned materials were taken for nutrient analyses. The rainfall during the study period was 288 and 212 mm in the short and long years respectively. Maize was sown at a constant density of 33,000 plants ha⁻¹ in all treatments at 0.5 m between rows and 0.3 m within the rows. This meant that *Leucaena* hedgerows in intercropping were at the center of two maize rows. Two seeds were sown at each hole, seedlings were thinned to

one per hill at first weeding (two weeks after sowing). Epiphytic granules were applied @ 5 kg ha⁻¹ at weeding at three-week stage to prevent the attack of maize stalk borer. The locust bean pyllid (*Phaeopyllia castaneae*) that appeared in epidemic proportion for the first time at Makindu Research Station in January 1993, caused serious damage resulting in virtually no locust bean leaf production during the "long rains" of 1993. From August 1993 the pyllid was controlled by chemical spray, @ 1.2 ml L⁻¹ water, at about three-week interval. Land preparation and interculturing maize were done by oxen, and within-row weeds were removed by hand.

Maize yield in each plot was estimated by harvesting four quadrats of 3.6 m x 3.6 m at random in the plots. In H2+G2L, maize was harvested row-by-row to assess the extent of hedge-row competition. Grain yield was adjusted to 14% water and grain yields expressed as constant dry weight. Locust bean harvest was determined by harvesting and weighing all the three hedge-rows separately. Sub-samples were taken for dry matter estimation which were oven dried at 60°C until the samples reached a constant weight.

Soil Water and Root Studies

Soil water changes in the unfertilized sole maize (H2-P) and hedge-row intercropped (H2+G2L) treatments were monitored using a neutron probe during 1993 "short rains". Six aluminum access tubes were installed at one edge of the H2+G2L plots in a triangle across the alley with the first tube positioned at 0.33L away from the hedge-row, between the locust bean (row of the plot) and the first maize row, and the

minimizing flow between the subsequent mesh rows. In the hole-mesh plots, three tubes were installed between rows distributed randomly. Shallow probe-mounds were recorded weekly at 15 cm depth intervals at the 50 to 120 cm zone. The water column in the top 30 cm was decreased progressively at 15 cm depth intervals.

Root observations were recorded during the 1996 stem count at both HC-F and HE+GHd plots. The hedges were pruned twice in this season. In the first pruning cycle, root samples were taken once (just week) before pruning and three times at 2-week intervals, after pruning. In the second pruning cycle, the first sampling was done one week prior to pruning, and three samples were taken at 1, 2, and 4 weeks after pruning. On each occasion, the samples in HE+GHd were taken at two spots, 1-9 m and 2-7 m from the hedges, on a transect across the alley. 18 transects were sampled over three replicates at each observation. Initial observations taken at small stem distances did not reveal large differences in roots along the transect, hence subsequent samplings were restricted to two spots. Coinciding with 36 and 34 (34.5 days after sowing), root samples were taken from three randomly chosen spots between rows at HC-F.

Root samples were collected using the coring method (Van Noordwijk, 1992) which allowed non-destructive, multiple root sampling. We used a 10-cm diameter pipe, from six depths: 0 to 11.5, 12.1 to 25, 25 to 35, 36 to 73, 73 to 100, and 100 to 125 cm. The pipe was driven to each specific depth using a hammer and then it was taken out of the ground to extract the soil sample with roots. The collected soil samples were soaked overnight in water, and wet-sieved the following day using a 200

a cone to separate roots from the soil. The root mass separated with organic debris retained on the cone was transferred to a polyethylene bag and stored in a refrigerator at commercial storage solution, within 24 to 36 hours. The tree and crop roots were sorted out manually from other organic debris, and the root lengths were measured. The sorted roots were stained with methyl-violet, and stained on a Delta T root scanner to determine root length density. Each sample required 1 to 2 person days to separate the tree and crop roots from the debris. The workers employed for the purpose were trained to distinguish the biomass and matrix roots from other organic materials. The precision of root sorting by the large number of workers employed was checked without their knowledge by a scientist sample containing known length of tree and crop roots. After sufficient training and practice, the root length measured varied within $\pm 2.5\%$ of the sample means among the workers.

The root data were not normally distributed, so they were log-transformed (log x) before subjecting to analysis of variance. The period of sampling, location of sampling site, soil depth were treated as factors at different levels. The statistical significance of treatment means was judged based on significant differences among transformed values.

Results

Soil Water Content

In 1925, short rains, the profiles of both sole and intercrop systems showed similar soil water content only in the top 30 to 45 cm depth during two storms and approximately for a week after the heaviest was passed in mid-December (Fig. 3.1). At lower depths the intercropped plots had less water than the sole system at all initial stages of maize growth. The total water stored in the 1.2 m soil profile was less in BE+GM than in BC-F throughout the season (Fig. 3.2). The soil under intercrop contained 38 mm less water than that under sole maize at the start of the season. The difference between the two systems narrowed to approximately 27 mm, but soil water in the intercropped plot was depleted faster than in the sole crop thereafter, by the end of the rainy season, water content in the former was 15 mm less than in the sole crop. The profile was never saturated during the rainy season with water because rainfall was inadequate, consequently, the soil appeared extremely dry by the end of the cropping season and the water contents in both cropping systems at the end of the season were even lower than those at the beginning of the season.

Within the intercrop, soil water content was generally higher closer to hedgerows in the lower part of the alley (i.e., slopes of hedgerows) than away from hedgerows on the upper part of the alley (i.e., shoulders of hedgerows) (Fig. 3.3). This difference in water distribution between locations in an alley was more marked as long as rains continued but narrowed after the rains had ended.

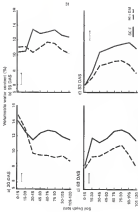


Fig 3.1. Root moisture status at four stages of maize growth in acid cropping (OC-II) and nitrogenous intercropping (II) + GJM systems in the 100% soil moisture (Bar indicate 100% (System-II) Dapchi)

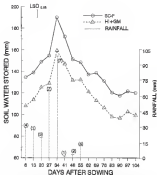


Fig 5.8 Soil water change in the 0 to 1.5 m profile in sole maize (SC-P) and hedgerow intercropping (H+GM) systems, and weekly cumulative rainfall during the 1980 short rains (numbers in parentheses are total rainy days).

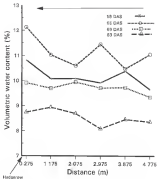


Fig 3.2. Soil water status in the alley at different distances from the hedgerow at four stages of mass growth during the 1993 short rains. Bars indicate LSD at 5%. Arrow shows the slope direction.

Table 2.2. Total root density at 0-10 cm (total) and nodules (nodule) (mean $\pm$ standard error) at 0-10 and 10-100 cm depth after Spring (2002)

Depth interval (cm)	0-10 cm		10-100 cm		Total	
	Root Density		Nodule		Total	
	Mean	SE	Mean	SE	Mean	SE
0-10 cm						
0-10	0.044	0.004	0.006	0.001	0.050	0.005
10-100	0.000	0.000	0.000	0.000	0.000	0.000
20-50	0.000	0.000	0.000	0.000	0.000	0.000
50-70	0.000	0.000	0.000	0.000	0.000	0.000
70-100	0.000	0.000	0.000	0.000	0.000	0.000
100-120	0.000	0.000	0.000	0.000	0.000	0.000
10-100 cm						
100-120	0.000	0.000	0.000	0.000	0.000	0.000
120-140	0.000	0.000	0.000	0.000	0.000	0.000
140-160	0.000	0.000	0.000	0.000	0.000	0.000
160-180	0.000	0.000	0.000	0.000	0.000	0.000
180-200	0.000	0.000	0.000	0.000	0.000	0.000
200-220	0.000	0.000	0.000	0.000	0.000	0.000
220-240	0.000	0.000	0.000	0.000	0.000	0.000
240-260	0.000	0.000	0.000	0.000	0.000	0.000
260-280	0.000	0.000	0.000	0.000	0.000	0.000
280-300	0.000	0.000	0.000	0.000	0.000	0.000
300-320	0.000	0.000	0.000	0.000	0.000	0.000
320-340	0.000	0.000	0.000	0.000	0.000	0.000
340-360	0.000	0.000	0.000	0.000	0.000	0.000
360-380	0.000	0.000	0.000	0.000	0.000	0.000
380-400	0.000	0.000	0.000	0.000	0.000	0.000
400-420	0.000	0.000	0.000	0.000	0.000	0.000
420-440	0.000	0.000	0.000	0.000	0.000	0.000
440-460	0.000	0.000	0.000	0.000	0.000	0.000
460-480	0.000	0.000	0.000	0.000	0.000	0.000
480-500	0.000	0.000	0.000	0.000	0.000	0.000
500-520	0.000	0.000	0.000	0.000	0.000	0.000
520-540	0.000	0.000	0.000	0.000	0.000	0.000
540-560	0.000	0.000	0.000	0.000	0.000	0.000
560-580	0.000	0.000	0.000	0.000	0.000	0.000
580-600	0.000	0.000	0.000	0.000	0.000	0.000
600-620	0.000	0.000	0.000	0.000	0.000	0.000
620-640	0.000	0.000	0.000	0.000	0.000	0.000
640-660	0.000	0.000	0.000	0.000	0.000	0.000
660-680	0.000	0.000	0.000	0.000	0.000	0.000
680-700	0.000	0.000	0.000	0.000	0.000	0.000
700-720	0.000	0.000	0.000	0.000	0.000	0.000
720-740	0.000	0.000	0.000	0.000	0.000	0.000
740-760	0.000	0.000	0.000	0.000	0.000	0.000
760-780	0.000	0.000	0.000	0.000	0.000	0.000
780-800	0.000	0.000	0.000	0.000	0.000	0.000
800-820	0.000	0.000	0.000	0.000	0.000	0.000
820-840	0.000	0.000	0.000	0.000	0.000	0.000
840-860	0.000	0.000	0.000	0.000	0.000	0.000
860-880	0.000	0.000	0.000	0.000	0.000	0.000
880-900	0.000	0.000	0.000	0.000	0.000	0.000
900-920	0.000	0.000	0.000	0.000	0.000	0.000
920-940	0.000	0.000	0.000	0.000	0.000	0.000
940-960	0.000	0.000	0.000	0.000	0.000	0.000
960-980	0.000	0.000	0.000	0.000	0.000	0.000
980-1000	0.000	0.000	0.000	0.000	0.000	0.000

† BC-P refers to both above ground nutrient fertilizer and 0-10 cm refers to nodules corresponding with roots

‡ Root density of both roots and nodules

§ Mean square values from the analysis of variance of log transformed mean root density in soil and subsoil

|| Mean square values from the analysis of variance of log transformed and root density in soil and subsoil

*, ** significant at 0.05 and 0.01 probability levels respectively

Maize Root Growth

Maize roots grew to 1.25 m depth by 70 DAD in both side- and intercropping plots (Table 3-2). However, at that stage, the roots were concentrated in the top 25 cm. The two cropping systems showed similar root densities below 25 cm depth. While the intercropped maize showed greater root density than sole cropped maize in the top 12.5 cm soil layer, the reverse was true in the subsequent 12.5 cm layer (Table 3-2). Maize roots increased by 2- to 3-fold from 35 to 55 DAD at all depths, except in the 12.5 to 25 cm depth. At maturity (55 DAD), the intercropped maize had higher root length per unit soil volume in the 75 cm profile than the corresponding value for sole maize. The observation at 70 DAD in HE+OM showed that maize roots continued to grow well beyond maturity. The depth-wise distribution of maize roots between rows along the hedge and at the middle of the alley was similar. The additional root growth had occurred below 25 cm in the maize along the hedgerows and below 50 cm in the maize further away from hedgerows. The combined root density of maize and beans in intercropping was four to five times higher than the root density in sole maize throughout the profile (Table 3-2).

Lucerne root growth

Although sampling was restricted to 1.25 m because of the difficulty in extracting the soil cores in the site, we observed that lucerne roots, unlike those of maize, had penetrated beyond the soft rock or "murrum" layers at 1.7 m depth. Roots of each hedgerow spread laterally beyond half the alley and covered the 3-4 m alley uniformly

(Fig. 3-4). Males were far exceeded, the burrows were near the surface (0 to 12.5), both species showed similar nest density in 12.5 to 75 cm area, but burrows were increased over those of nests with depth below 75 cm. (Table 3-2, Fig. 3-4)

Observances to burrow roots were observed only in respect to sampling time, depth-wise distributions, and interactions between these factors (Table 3-3). Following the first pruning, burrows seemed to have produced a new batch of fine roots which were concentrated more in the middle of the alley than after the hedgeprunes (Fig. 3-4). Following the second pruning, 3-weeks after the first pruning, no additional root growth was noted and whatever changes observed in burrow root density were similar across the alley.

Leucopis root density was highest in the 12.5 to 25 cm soil depth where it also had maximum changes from 0.12 to 6.58 cm/cm² during the season compared with the changes from 0.05 to 0.11 cm/cm² in other depths (Fig. 3-4). The first sampling taken after first pruning close to hedges indicated decreased root density in 12.5 to 25 cm depth, but increased root density below 50 cm. The next sampling done about four weeks after pruning indicated increased root density in the 12.5 to 25 cm depth to the same level as at the previous sampling. However, the subsequent sampling, three 43 days after pruning, showed increased root density throughout the 1-25 cm profile. Samples taken in the middle of the alley showed moderate increases in root density below 12.5 cm in the first two samplings after pruning. At 43-days after pruning, the root density was markedly higher than that observed before pruning throughout the soil profile.

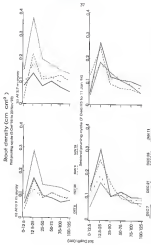


Fig. 1 Live density changes of three prawn species during the two prawning cycles at two different locations. Live densities were 100 cm⁻² in 2013 and 2014.

Table 3.3. Mean square values from the analysis of variance of log transformed snout-vent length by river flow sampling, forest and locusts root density, carbon area and weight ratio, sampling, forest as background intercepting

Source	Forest root			Locusts root		
	df	Sum of squares	df	Sum of squares	Sum of squares	Weight
Thompson	10	1.834*	12	0.944**	1.864**	0.003
Time	3	0.824	2	2.032**	2.226**	0.0073**
Forest (2)	20	0.827	110	0.790	0.896	0.0012
Locusts	1	0.769	1	0.017	0.0002	0.00024*
Time x locusts	3	0.406	7	0.395	0.274	0.00018*
Forest (2)	40	0.863	120	0.102	0.284	0.00012
Depth	3	1.882**	3	0.509**	10.819**	
Time x depth	10	1.541**	20	0.409**	0.869**	
Locusts x Depth	3	0.182	3	0.128	0.186	
Time x locusts x depth	10	0.277	21	0.084	0.172	
Forest (2)	200	0.463	1040	0.104	0.152	

*, ** are significant at 0.05 and 0.01 probability levels respectively

Lawrence root density in the first week after second pruning decreased markedly to 11.5 to 23 cm depth at both locations of the alley. The second foraging after pruning recorded a significant reduction in root density in the top 75 cm. root depth intermediate 33 cm root depth. Averaged over two locations in the alley and two depths up to 1.15 m, the root density increased by 30% two weeks after first pruning, it did not show much change during the next two weeks, but showed 300% increase during the subsequent two weeks (Fig 3.5). The increase in root density coincided with increase in seasonal rainfall and attained a peak value of 0.043 cm cm⁻² around 42 days after pruning. Although rainfall continued beyond this date, root density decreased to 0.040 cm cm⁻² within two weeks. The first sample taken one week after second pruning showed a further 11% reduction compared with that a week prior to pruning. The sample taken two weeks later showed a small increase, however, the last sample taken four weeks after pruning again recorded 11% reduced root density compared to that before pruning. The root surface area followed almost the same pattern as that of root density. Both root density and root surface area values at the end of the season were similar to those at the beginning of the season.

Immediately after shoot pruning, root weight decreased despite of increase in root density (Fig 3.6), but weight increased after the onset of mass rootling maximum on 6 weeks after pruning coinciding with the highest root density. The root weight decreased 6 weeks after first shoot pruning, second shoot pruning and this continued until 2 weeks after the second pruning when the lateral weight was recorded. Rapid

on root weight changes over the growing period, the total root biomass added to the soil was 5.3 kg ha^{-1} which contained 7 kg N and 0.3 kg P ha^{-1} (Table 3-4).

Yields

The unfertilized sole maize yielded 1.48 Mg ha^{-1} during 1993 'short rains' and 1.11 Mg ha^{-1} during 1994 'long rains' (Table 3-1). There was no response to fertilizer or other inputs, because the two sole maize systems, the yields were not different. On average, the intercropped maize yields were lower than the unfertilized sole maize by 49% and 38% in 1993 'short rains' and 1994 'long rains,' respectively. Similarly, the cereal yields of intercropped maize were 28 to 42% lower than those of sole-cropped maize. The row by row grain yields clearly reflected the treatment effects on per ha yields (Fig. 3-4). The first three rows on the lower part of the alley (i.e., close to hedgerows on the upland) produced higher yields than the three rows on the upper part of the alley. Among the three rows of lower alley, the middle row yielded more than the other two rows. However, there was no clear trend in the cereal yields across the alley in intercropping.

Discussion

The amount of available water in a hedgerow intercropping situation depends on the current season rainfall and the amount of water depleted by hedgerows in the previous season. The hedgerows, which are perennial, absorb the residual water in the

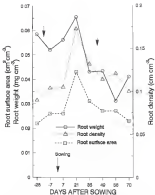


Fig 2.5 Changes in weight, surface area, and density of lucerne roots during the 1993 short rains. Arrowheads indicate the pruning events

Table 3.4. Meanest content of bromine, boron and total elements added through glass inserts of landscape carpeting.

Inserts	Bromine (kg ha ⁻¹)	Boron (kg ha ⁻¹)	B		Total elements added (kg ha ⁻¹)	
			M	P	M	P
Short rolls (1075)	1403	Prufar	± 13	0.17	47.9	2.1
Long rolls (1084)	1413	Prufar	± 20	0.06	7.0	0.2
Long rolls (1084)	1449	Prufar	± 46	0.13	41.1	2.4

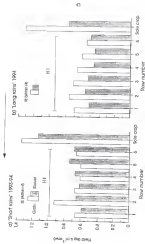


Fig. 3.6. Mean probability of detection across the background microscoping (HII=HII) and spectroscopy (HII=HII) on the (a) short name and (b) long name. Arrows indicate the slope direction.

Table 3.3 Mean and income gains in job creation and business micro-empowering systems in Macedonia, Europe

Treatment	Mean (M) in %		Bridge Income (M in %)	Total Income (M in %)
	Crash	Sever		
Short run (1995)				
BC-F	1160	1001		6077
BC+QM	1276	1208	1431	3026
BC+IF	1795	1250		5000
LSQ ₁₀₀	602	640		1421
Long run (2006)				
BC-F	2035	1677		1450
BC+QM	1571	1681	1459	3752
BC+IF	2244	1814		1488
LSQ ₁₀₀	771	749		1271

post-harvest periods after maize is harvested). Consequently, soil water status under hedgerow intercropping was lower than that under sole maize at the beginning of 1993 'short rain' (Fig. 3.2). Moreover, maize in 1993 'long rain' had failed due to poor rains, but the hedgerows removed the water excess in the residual water (from 1992 'short rain'), depleting the soil water in intercropping to a very low level by the beginning of 1993 'short rain'. The 'short rain' were not adequate to recharge the profile (Fig. 3.2). Soil water in intercropping reached the same level as in sole maize only in the top 45 cm for short periods following continuous showers and when the hedgerows did not transport much for some time after they were pruned (Fig. 3.1 and 3.2). In addition to the low amount of available water under intercropping, continuous utilization of water by the hedgerows resulted in competition for water between the hedge and crop species. As a result of low water availability, the maize root density per unit of above ground maize dry matter was more in intercropping than in sole cropping (Table 3.2). The total root density of maize and legumes in the intercropping system was 3- to 4-fold higher than that of sole maize at different soil depths. Such a heavy root density in intercropping is expected to increase demand for water throughout the growing period. Therefore, it seems that while low soil water availability forced the plants to produce more roots on the one hand, the higher root density increased water demand for water on the other.

There was no runoff at any stage in water groups, so all the seasonal rainfall was assumed to be available for crop and tree growth. The amount of rainfall used by the sole and intercrop during the crop-growing period was probably similar as indicated by

similar water status at the time of crop harvest under both systems. However, the total water used by the intercropping system, as an annual basis was more than that used by the sole crop because the hedgerows used water during the non-cropping periods as well. In spite of that, the total biomass produced by the hedgerows intercropping system was not different from that of sole maize, which suggests that water use efficiency of biomass was lower than that of maize (Table 3.3). In spite of 25% less rainfall, maize in the 'long rain' produced similar yields as in the 'short rain' because the growing period was longer by four weeks. The lower evaporation demand during 'long rain' of 'long rain' mean pan evaporation of 3.8 mm day^{-1} compared with 'short rain' mean of 6.7 mm day^{-1} included the cropping period as well as improved the harvest index of 'long rain' maize (28% compared with 20% in the 'short rain'). Moreover, the rainfall was more effectively utilized in 'long rain' as storms were evenly spread over a longer period than in the 'short rain'. The lack of sole maize response to fertilizer suggests that the soil nutrient status was adequate for the amount of rainfall received at the site.

Tree-Crop Competition for Growth Resources

The significant water yield reduction observed in intercropping in this trial is in agreement with many other studies on the stressed tropics (Dexter and Morgan, 1983; Rao et al., 1981; Singh et al., 1985). The yield loss could be due to competition between the sole crop for surface growth resources such as light, water, and nutrients. As hedgerows were present just before, and not weeks after, maize sowing, there was little

if any, shading of crops by the hedger in the alleycropping system. Moreover, as maize rows close to hedgerow yielded almost the same as or more better than the other areas in the alley (Fig. 3-4), light was not a limiting factor in the intercropped maize in this study. The lack of crop (maize) response to fertilizer further proves that nutrient use were not a limiting factor in hedgerow intercropping (Table 3-2). This leads to the conclusion that competition for water between maizans and maize was the major cause for reduced maize yields in hedgerow intercropping. On the other hand, the water stress in intercropping was lower than in sole maize throughout the season (Fig. 3-3).

Influence of Pruning on Luccuma Root Growth

The effect of pruning on root growth was not consistent in the two pruning cycles. While root growth increased after first pruning done before the onset of rains, the roots decreased after second pruning done towards the end of rains. Above-ground pruning is known to cause death of fine roots because of inadequate carbohydrate supply (Florent and Andrieux, 1991; Rousseau et al., 1993; Nygren and Campos, 1993; Vogt and Blomfield, 1990). Root death is also caused by natural senescence and environmental stress such as drought, and the magnitude of root death caused by drought seems to be much higher than that due to other factors. Stress-induced root death occur mostly in the dry season. The first pruning did not induce root death because the root system was least active towards the end of dry season. Root growth started with the onset of rains which peaked in late November when there was no water stress.

However, as the rainfall declined and water stress set in, the process of root death had already started. Consequently, there was considerable death of roots following the second pruning which was exacerbated by the rapidly depleting soil water. It was not possible in this study to separate the effect of pruning on root growth from the influence of increased water availability after a prolonged drought at the beginning of crop season and water deficiency at the end of the season. The root turnover calculated from root weight changes over the season (0.5 t/dg ha^{-1}), could be an underestimate of actual root death because formation of new roots and degeneration of older roots might be occurring simultaneously during the plant's growth (Fagerl, 1982).

Two conclusions emerge from this study: 1) in arid/semi arid where water is often limiting, stripcropping is water-productive because of the competition of legumes with crops for water and 2) nutrient assimilation through the root turnover of legumes for crop growth is small, particularly in relation to that of aboveground biomass.

CHAPTER 4

ABOVE- AND BELOW-GROUND COMPETITION AT THE TUBEROUS/ROOT INTERFACE AS INFLUENCED BY TERR. PERENNIAL

Introduction

Periodical pruning of the hedge species is one of the important plant-management operations. Apart from providing nutrient-rich biomass that can be used as a nutrient source for the interplanted food crop (Xiang et al., 1981; Iqbal, 1983), pruning also decreases the above-ground competition for light between the tree and food crop species. Pruning, however, may not eliminate the below-ground competition for nutrients and water between the species. Among the below-ground growth resources, soil water may be a more critical factor than nutrients in the semi-arid tropics. As most of the semi-arid regions receive rainfall during a short period and at relatively high intensity, most of the soil water is lost before the annual crop can utilize it, and, the water that falls after the cropping season is, naturally, not utilized by the crop. Inclusion of a woody perennial in the annual cropping system may result in more efficient utilization of rainfall throughout the year by the perennial species. Moreover, the deep and wide-spread root system of the perennial species may tap the soil water from the deeper layers that are inaccessible by annual crop roots. However, under such circumstances, it may not be practical to fully realize the biomass-production potential

of the woody component for the benefit of crop production, and in any case, in most parts of semiarid tropics, the total annual rainfall is hardly adequate for any crop (Singh et al., 1985; Rao et al., 1990; Dasso and Mungai, 1993).

The below-ground competition for water between the trees and the crop, and the consequent water stress may alter the forest crop's photosynthesis partitioning into above- and below-ground parts (Lambert et al., 1986). This may result in increased root production as a response to stress and ultimately lead to poor above-ground growth and low yield (Kali and Bawa, 1992). Studies of this nature, however, have not been undertaken in silvocropping in the semiarid tropics.

Theoretically, it is likely that the extent of below-ground competition may be reduced through foliage pruning because of root system modifications (Easowari and Dossan, 1982). Since periodical pruning stops the photosynthetic activity of the woody species for some period, there might be decreased root growth rate after above-ground pruning, due to lack of energy source (Purves and Anderson, 1990; Eriksson et al., 1993). This relatively low root-activity of the pruned tree compared to an unpruned one may reduce the magnitude of below-ground tree-crop competition; the influence of pruning on root activity of the woody species is, however, not clearly understood. With this background, the present investigation was conducted with the objectives to (1) study the pattern of soil water change in lucerne-based tree-crop intercrop plots compared to the sole lucerne plots, (2) assess the changes in maize root growth as influenced by soil water status and tree root density, (3) evaluate the impact of shoot pruning on the root density of the lucerne hedge at various distances and

inputs compared to suppressed trees, (4) investigate the changes in root system of tree species because of cropping, and (5) evaluate the relative influences of light and root competition on crop yield.

Materials and Methods

The site

The study was conducted at the same experimental station mentioned in Chapter 3. The physical and soil characteristics of the study site were similar to the site described in Chapter 3. The study was conducted from October 1992 to February 1993, the period covered three cropping seasons: "short rain" of 1992, "long rain" of 1993, and "short rain" of 1993. The rainfall received during the short rain of 1992 was above the average (190 mm), but it was below average (246 mm) during the short rain of 1993, the long rain of 1993 failed, with only a few rainy events at the beginning of the season.

Experimental Details

The experiment had been started in 1989 with *Acacia* (*Acacia leucophloea* Lam.) and maize (*Zea mays* L.) as the woody and food crop components. There were four treatments, in a randomized complete-block design with three replicates. The treatments were: (1) suppressed *Acacia* grown with maize, (2) pruned *Acacia* hedgerows grown with maize, (3) pruned *Acacia* hedgerows grown without maize, and (4) maize only (with maize). The plot size was 10 m x 10 m, *Acacia* plants were in a row in the

rows with 0.3 m within row spacing. On each side of the Louisiana row, ten rows of maize were planted and spaced at 0.75 m between rows and 0.3 m within a row. At the time of initiation of this study, the upland Louisiana plants were approximately 3 m tall, its canopy appeared to cast shade on the first 3 to 4 rows of maize from both sides of the row. Louisiana budgets were pruned twice during a season: the first at 3 to 5 weeks prior to the start of the season and the second at 7 to 8 weeks after the first pruning. For the first time since 1993, the Louisiana plants were sprayed from August 1993 to October 1993 with Dinoseb at 1.3 ml L⁻¹ against pyralid moth (*Stenoprylla cultrata*) at three week intervals, seven incidence of the pest left the Louisiana plants healthy during the long rains of 1993. The plants were manually weeded twice after maize sowing with flaming done along with the first weeding. Deltamethrin granules were applied at 3 kg ha⁻¹ at intervals at three-week stage to prevent stalk borer incidence. The maize was grown under raised, rectangular mounds. Each plot was separated from other plots by inserting a metal sheet all around to 50 cm depth to prevent any interference from the neighboring plots.

Soil Water

Soil water content was monitored weekly using a neutron probe at all treatments. Five aluminum access tubes were installed at five distances on each side of the Louisiana rows or center of the plot. The tubes were positioned in the rows from which the soil samples were collected. Soil water was monitored from eleven layers, each 15 cm deep, from the surface to 165 cm depth. Soil water content in the top 30 cm was

quadratically monitored at two 12-cm depth intervals. All soil-water data were expressed as volumetric water content (%) as suggested by Gardner (1984). The data were subjected to analysis of variance and comparisons were made using Least Significant Difference (LSD) at 5 %.

Root Density

Root samples were collected during the short rains of 1992 and 1993, and, the samples were collected in all the four treatments, during the harvesting stage of maize (59 DAAE - Days After Anthesis), at 1, 125, 2, 425, 4, 625, 5, 825, and 7, 1125 m away (upwind) from the center of the plot on either side of treatment area. At each spot, ten root samples were collected at 0 to 15.5, 15.5 to 31, 31 to 46, 46 to 61, 61 to 76, 76 to 91, and 91 to 1125 cm depth intervals. Considering the possible variability of root data from one set of sample within a plot, a mixed set of samples was collected from each plot nearly at positions corresponding to the four sampling spots. Thus, within a plot, four samples were collected and they were considered as sub-samples from each replication.

Root samples were collected, preserved, weighed, and analyzed as the root mass as explained in the "Root density" section of Chapter 3. The statistical details of root data are provided in Table 4.1.

Table 4.1. Mean square values from the analysis of variance of log transformed locusts and mean root distance over two seasons at the tree-leg interface experiment.

Source	d.f	Mean sqs, '92		Mean sqs, '93	
		Mean	Locusts	Mean	Locusts
Block	2	3.876**	3.388**	1.146**	1.778**
Treatment	2	2.827**	30.758**	1.224**	12.318**
Distance	4	0.473**	4.468**	0.363**	1.000**
Depth	3	12.623**	3.383**	1.779**	0.494**
Treatment*Distance	8	0.934**	0.853**	0.045	1.873**
Treatment*Depth	10	0.348**	0.723**	0.014	0.471**
Distance*Depth	10	0.127	0.180	0.008	0.171
Treatment*Distance* Depth	40	0.194	0.258	0.014	0.135
Error	178	0.148	0.193	0.024	0.178

** refer to significant at 0.001.

Light

Light available to maize was also measured every week using a quantum sensor during the short term of 1993. Photosynthetically Active Radiation (PAR, $\mu\text{mol m}^{-2} \text{s}^{-1}$) was recorded at the same position as the root samplings. Expressing PAR in relative terms could be more useful in understanding the above-ground competition between widely and narrowly species which is the one of the main objectives of the study. The data were, therefore, expressed as the amount of light received by the maize grown with area, as a percentage of that received by sole-crop maize. The collected data were statistically analysed and comparisons were made using LSD at 5%.

Maize Yield

Maize was harvested row-by-row and plot¹ was measured only for 4 m width leaving 2 m as either end as border. Maize grain yield were reported separately after adjusting the grain water content to 14.5%. Total maize yield refers only to the above-ground biomass (Table 4-2). In the lucerne grown plots, maize yield was expressed as the percent of control treatment (sole maize) yield. Relative influences of above- and below-ground competition on maize yield were quantified using a regression analysis. For the regression analysis, the light and root data collected at 55 days of maize were used.

Table 4.3 Mean (and yield at various distances in different treatments at the two crop seasons during the short runs of 1995 and 1996)

Distance (m) ^a	Short run of 1995			Short run of 1996		
	Total+crop	Edge+crop	Main only	Total+crop	Edge+crop	Main
				kg ha ⁻¹		
0.75	506	367	372	483	501	392
1.50	851	593	524	747	597	511
2.25	873	521	543	736	521	534
3.00	928	581	577	763	577	519
3.75	941	588	588	841	571	579
4.50	883	573	583	772	536	593
5.25	576	270	531	116	359	531
6.00	589	215	595	829	197	597
6.75	772	371	581	136	369	583
7.50	318	368	614	127	383	341
LSL ^b	851.5			756.5		

^a Percent of maize row from the first row to the end of crop treatment

^b LSL is a computer program

Results

Soil Water

Although soil water was monitored on a weekly basis, considering the enormous amount of data, detailed water information is presented only for four critical growth stages (vegetative, tasselling, silking, and milking) of maize. Moreover, because of the failure of the long rain of 1993, only short-term data of 1993 and 1995 are presented. In both short rainy seasons, soil water status was always lower in the tree+crop treatment compared to the hedge+crop and sole maize plots. At the beginning of the short rains of 1993, soil water status of the tree+crop treatment was less than 11 % in the top 30 cm layer compared to that of 20 to 25 cm layer of the sole maize (Fig. 4-1). During the short rainy season of 1993, although the tree+crop treatment had the lowest soil water of all the three treatments, continuous rainy events at the beginning of the season led to soil water improvement in all the treatments. However, the influence of rain on soil water increase was slower in the tree treatment compared to the hedge+crop or sole maize treatments. Soil water status of hedge+crop was lower compared to the sole maize plots, the difference was distinct even after the beginning of the cropping season. Soil water status was of similar pattern among the various treatments during the short rains of 1995, consequently, soil water status under the sole maize treatment was higher than that of the tree and hedge treatments. At the end of the short rains of 1993, however, the difference was not as significant as observed during the short rains of 1995 because of rains during the later part of the 1993 season.

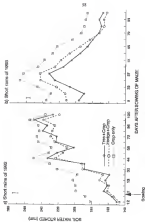


Fig. 4.1. Root mass stored in the 0 to 1.00 m profile in various treatments during shoot mass of 1992 and 1993. Bars indicate L.S.D. at 5%.

Higher soil water depletion occurred until travelling steps of maize, and slower after that in all the treatments (Fig. 4.2 and 4.3). During both seasons, significant soil water changes were observed in the top 50 cm in the lucuma-based treatments and in the 30 to 60-cm layer in the case of sole maize. Soil water status did not decrease beyond 1.35 m depth in the sole maize whereas, in the lucuma treatments, it decreased up to 1.65 m depth. Soil water status in the hedge+crop treatment was not different from that of the tree+crop treatment at the end of both seasons (Fig. 4.3). In lucuma, plus, the soil water was always low near the woody plants.

Root Density

Lucuma

In both seasons, lucuma trees had at least twice as much root density (Fig. 4.4 and 4.5) as of lucuma/hedge grown with and without maize (Fig. 4.6, 4.7, 4.8, and 4.9). Also, lucuma root densities in all the three plots during the short season of 1992 were, 100% higher compared to those of 1993, the root density decrease during the short rains of 1993 occurred mostly in the top 30 cm layer. Then root density decreased progressively from the base with increasing lateral distances (Fig. 4.4 and 4.5), density was always higher in the top 30 cm layer which accounted for 50-70% of the total root density in the profile. Hedge grown with and without maize, however, had uniform root density at all lateral distances from the row (Fig. 4.6, 4.7, 4.8, and

Figure 4.3: Real water stress at vegetation (25 DAD), Dye (after 5 years), seedling (27 DAD), seedling (31 DAD), and seedling (35 DAD) stages of maize during the short rain of 1992. Data estimate $h_{\text{DAD},\text{veg}}$.

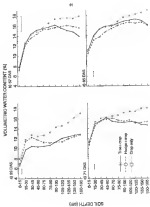
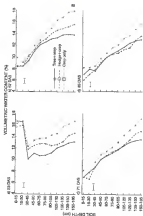


Figure 4.3: Red vector starts at magnitude 125 (DAB), then after forward, reaching 675 (DAB), ending 675 (DAB), and ending 180 (DAB) stages of noise during the silent state of 100. Note labels 1,2,3,4.



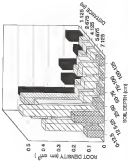


Fig 4.4 Root density of leucaena trees grown with crop at various distances from the tree row at a trypsin-resistant mite infestation during the 'shoot' phase of 1990. Statistics are given in Table 4.1.

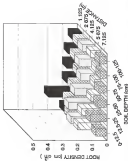


Fig 4.5. Root density of leucaena trees grown with maize at various distances from the tree row at a tree/crop interface during the 'short rain' of 1993. Statistics are given in Table 4.1.

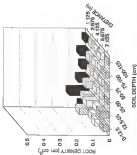


Fig 4.6 Root density of *Leucaena* hedgerows with maus at various distances from the hedgerows at a tree/crop interface during the 'short rains' of 1992. Statistics are given in Table 4.1.

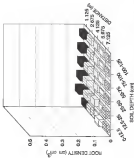


Fig 4.7. Root density of leucosasa hedge grown with maize at varying distances from the tree row at a tree/crop interface during the 'short rains' of 1993. Statistics are given in Table 4.1.

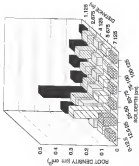


Fig 4.8. Root density of lucern hedges grown without cross at various distances from the hedge for a lucern plot subjected during the 'short rains' of 1992. Subscripts are given in Table 4.1.

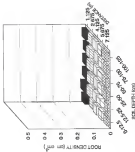


Fig 4.8 Root density of leucaena hedge grown without crop at various distances from the hedgerow at a tea/crop interface during the 1993-1994 season. Statistics are given in Table 4.1.

4 %), in addition, the densities were similar throughout the profile. In both seasons, root densities of hedge + crop and hedge only treatments were similar.

Mass

Root densities of maize were similar in both the sole- and the (legume)-based treatments. In both seasons, maize root density was uniform at all distances from the hedgerow, and was similar to that of sole maize plots (Fig 4.10). Under legume trees, maize root density increased progressively with the distance from the tree row; during the short rains of 1993, maize root density at 7.125 m distance from the tree row was four times that at 1.125 m whereas the values were similar during the short rains of 1992 at all distances (Fig 4.11 and 4.12). During the short rains of 1993, at 1.125 m away from the tree, root density was uniform throughout the 0-25 m profile, at other distances 60 to 70 % of the total root densities were observed in the top 20 cm depth. In contrast, during the 1992 short rains, root densities were similar at all distances and they decreased progressively from the surface layers with approximately 70% of the total density being present in the top 20 cm layer. Between the two seasons, maize produced more roots during the short rains of 1993 in all the three treatments, especially beyond the 20 to 70 cm depth interval. While comparing the maize root density in the sole-maize treatment during the two seasons, three times higher root density was observed in all the depth intervals during the short rains of 1993, but, the root density distribution in the profile was of similar pattern during both seasons.

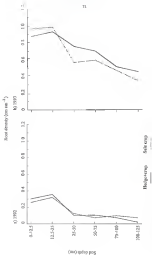


Fig 4.18. Root density of mature green with and without tree at the trenching interfaces during the plant years of 1992 and 1993. Statistics are given in Table 4.1.

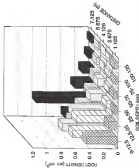


Fig 4.11. Root density of midsize grown with trees at various distances from the tree row at the tree-crop interface during the 'short rains' of 1992. Statistics are given in Table 4.1.

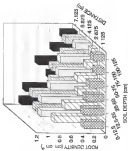


Fig 4.12. Mean root density at different distances from the tree row at the tree/crop interface during the 'short rains' of 1993. Statistics are given in Table 4.7.

Light

In the hedge+crop treatment, where the hedges were periodically pruned, the crop was well shaded by leucena. In the case of tree+crop treatment, the crop canopy was found to intercept only 35% of light at 1.325 m (Fig. 4.14) compared to that of the sole crop. The percentage of light available in the wheat-must treatment, compared to the sole crop, increased progressively from the center to the end of the plot with about half light beyond 3 m distance from the tree. Throughout the season, the light intensity was similar at all distances.

Yield

During both seasons, maize grown with leucena tree produced less than the sole crop (Table 4.2; Fig. 4.15). The maximum yield obtained at the edge of the tree+crop plot was 2158 and 1427 kg ha⁻¹ during the short rains of 1992 and 1993 respectively. These quantities were just 38% of the sole crop yield (Table 4.2). In the tree+crop treatment, the yield increased from 4.30 m distance towards the edge of the plot coinciding with increased light interception. Yield at the last row of maize nearest the tree was <10% of the sole maize yield in both seasons (Table 4.2). Maize yields with leucena hedge were similar during both seasons, and was approximately 50% of the sole maize yield. Maize yield at the last row of hedge+crop plot was higher than that of other rows which yielded equally. The yield during the 1993 short rains was better than that of 1992 in all rows of hedge+crop treatment except in the last three rows at

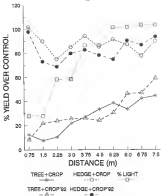


Fig 4.15 Relative yield of maize when grown with tree and hedge at various distances at the tree/crop interface

the soil of the plot. The regression analysis showed that the amount of light intercepted by maize influenced the maize performance. The regression analysis also demonstrated that species diversity of biomass did not have any significant influence on maize performance.

Discussion

Soil water

Relatively higher soil water status in the hedge + crop treatment compared to the tree-based treatment could be because of smaller transpiring canopy of the former. In addition, since the hedges were grazed four weeks before the onset of rains, transpiration loss might have been less. The soil water content was always higher in the sole maize plots compared to the biomass-based plots, which can be attributed to the absence of any transpiring plants in those plots beyond the season (Fig 4 (i)).

Similar observations were also reported in the natural region by Daxel et al. (1992) in Hyderabad, India, and KIRAP (1992) in Michalica, Kenya. As can be expected, with the onset of rains soil water status improved in all the treatments. But the "recharging" occurred at varying rates in different treatments. In the tree + crop treatment, the recharging was slower than in the hedge + crop treatment (Fig 4 (i)). One reason for this is that the soil water content was the lowest in the tree + crop treatment at the beginning of the season. Continuous transpiration by the tree throughout the year, might have led to drastic depletion of soil water in the plots. In an earlier study conducted at the same site, the biomass trees were reported to have utilized 70 % of the

available water compared to 1971 by soil water treatments (ICRAF, 1973). Water loss could have occurred through soil evaporation as well, but that was not studied in this experiment.

During the short rains of 1971, although the seasonal rainfall was almost twice as that of 1963, most of the rainy events occurred during the later part of the season which might have adversely affected crop growth at the early stage. During the short rains of 1971, the rainfall received was higher savings and most of the rainy events occurred before the tasselling stage of maize, this might have led to the early improvement in soil water content in all the plots. This higher (soiled soil) water availability during the vegetative stage, when the water demand was at its peak might have led to the efficient use of soil water (Fig. 4.2 and 4.3). It is clear that rainfall received during the early stage of season is more important than that received during the later part of the season.

While comparing the soil water depletion-pattern among the treatments, at both seasons, soil water depletion occurred at the deeper layers and at least 4-5 m away from the furrows rows. Although the magnitude of soil water exploitation was actually low in the lucuma hedge+crop plots at both seasons, increased soil water demand of lucuma hedges and normally growing maize rapidly depleted in the later part of the season. This demonstrates the ability of lucuma plots to exploit larger volume of soil for water uptake, the finding was similar to the observations made by Dierick et al. (1991) in a pineapple (Cajana) against weghem (Sorghum bicolor) hedge-row intercropping study.

Root density

Within the lucuma-based plots, root density was higher near the lucuma roots compared to other distances away from the tree (Fig 4.4 and 4.5). Between the lucuma treatments, root density near the tree roots was higher in the uprooted-tree treatment than in the hedgerow treatment. In general, root density of lucuma hedges was lower than that of the roots (Fig 4.4, 4.7, 4.8 and 4.9). This is a clear indication that the root density decreased when the plants are short-pruned. Bazzaz and Dumas (1992), also working with citrus, had observed similar reduction in root density subsequent to branch removal. In the present study, the top 30-cm layer had higher root densities in the root domain even very much similar to all the depth intervals in the lucuma hedges. Reduction in root density of lucuma plants, both trees and hedges, during the short cycle of 1995 compared to the short cycle of 1991, could be because of two reasons. First, the failure of the long rains during 1995 might have led to very low soil water status, and death of roots in the top 30-cm layer where we observed 70-75% of the total root density (the results were similar to the findings of Ilariu and Taylor (1979) who observed more root activity and water depletion at the base of the saplings (*Eucalyptus maculata* plant). Second, the pyralid outbreak during the long rains of 1995 caused defoliation and reduction of photosynthesis, and therefore caused a severe reduction in the supply of carbohydrates to the roots even for short maintenance responses.

There was no difference in the root density of lucuma hedges grown with red mulch or black (Fig 4.4 and 4.9), this means that interplanting of crops did not

influence root production in the woody perennial. However, the presence of the woody perennial influenced the root characteristics of grasses. In the case of maize grown with lucerne trees, the root density was lower at 1-120 cm from the soil where the lucerne trees also had higher root density and the soil water was low (Fig. 4-12 and 4-13). As with the findings of Hamblin and Tennant (1977), James et al. (1989), and Nakamura (1993), root density in the tree-free treatment was higher throughout the soil profile because of low soil water content compared to other treatments. As with most agroforestry crops, soil water stress increased the root density of grasses (leading to root to grow deeper). This was evident during the short rains of 1993, when the rainfall was below normal and the maize root growth was affected, compared to the short rains of 1992 when the rainfall was above normal, suggesting that root growth occurred in the deeper layers when the soil water content decreased in the top layers. Allmaras et al. (1975) had also observed higher rooting depth for maize when the depth to water table was high.

However, root density of maize grown alone and with lucerne hedge was similar in the deeper soil layers which shows that interference effect of lucerne roots on maize roots was significant only in the surface layer. The single factor that influenced maize root growth most was soil water content as was evident through the highest root density of sole maize during the short rains of 1993 compared to the short rains of 1992. Pfeiffer et al. (1981) working with wheat (*Triticum aestivum*) under water-limiting conditions had also reported similar observations.

In conclusion, the study shows that shoot pruning reduces the root density of the woody species which in turn decreases the water uptake. Pruning, therefore, seems to be an important management practice to reduce both above- and below-ground competition.

Light and Yield

Light availability was low near the juvenile trees, where only 35-33% of light was available, compared to that of the site-mean, throughout the season (Fig. 4-14). Because of higher water demand, maize plants in the first four rows from the tree edge have prioritized their carbohydrate allocation for root and production than shoot production. This was evident with higher root density and better above-ground growth with increasing distance from the center of the plot. However, the influence of shading and limited water availability confounded their effect on maize yield. The regression analysis (Eqs. 1) combining both these factors showed that light is more influential than water.

Based on the regression equation (Eqs. 1), light effect was significant and it decided the extent of competing ability of maize. In re-simulation, maize performed similarly in the tree-free zone treatment during the short runs of 1992 and 1993 although the 1993 season received twice as much rainfall as in 1992. These observations showed that even if there is no competition for water, presence of above-ground competition may affect the photosynthetic activity of maize which may result in poor growth. Combination of continuous water demand by the tree and shading to maize resulted in

poor performance of maize under low-rain treatment compared to rain maize. The percent yield increased as light interception increased at increasing distances from the center of the plot. The current experiment was, however, not designed to separate these effects of above- and below-ground interactions.

Excess water drained by the lysimeter ledges and the absence of shading on crops enabled normal growth of maize under lysimeter ledge plots. Therefore, it can be concluded that growing maize with periodically pruned ledges is more productive than growing with repeated rains.

CHAPTER 5 ROOT DYNAMICS OF *LYTICORNIS CASIOCEPHALA* AS INFLUENCED BY PLANTING METHODS AND SHOOT PRUNING

INTRODUCTION

Factors of exposed performance of belowground intercropping in the semiarid tropics led to consideration of several management options to reduce competition between the woody and crop species. The management of below-ground competition was thought to be possible through modification of the tree-root systems (Van Steenburgh et al., 1987). These management options of both plant components include different planting patterns (Williamson and Connor, 1990), depth of seed sowing (Sharma et al., 1987), root pruning (Hughes et al., 1994) and deep plowing (Schroth et al., 1993). It is well known in the case of cereal crops such as rice that manipulation of seedling or sowing in direct seeding results in better root development (e.g., Sharma et al., 1987). Similarly, Williamson and Connor (1990) found poorer vegetative and reproductive growth of *Pinus patula* trees when the plant root systems were modified by barriers (isolating the root system of a plant through a metal or polyethylene sheet) compared to normally planted trees.

In an attempt to reduce the competition between yellow tree (*Albizia molleoides*) and Kari plant (*Acacia drepanolobium*), Hughes et al. (1994) pruned the roots of yellow trees

through deep ploughing, but, root pruning did not reduce the competition from the perennial species. Root spread (horizontal) was very deep. In agroforestry intercropping systems, using a barrier was considered an effective way of containing the below ground competition (Wiley and Bailey, 1981). Under agroforestry conditions, however, an evidence has so far been established on the effect of different tree-planting methods on root growth of the woody perennial. Singh et al. (1999) used barriers to restrict the root system of the woody species in the perennial lands of western India, the polyethylene barriers were started to a depth of 50 cm after two years of normal root growth. Restricting tree root growth did not, however, reduce the competition for water between the woody and alleycropped herbaceous species. The effect of using a deep barrier right from planting the tree has not been investigated.

Root pruning, another management technique being practiced in agroforestry, offers the opportunity to recycle nutrients from leaf litterfall in soil for the benefit of food crop. Root pruning is not, however, considered as a means to reduce the extent of below-ground competition. Pivates and Anderson (1991) examined the impact of pruning on root growth in lucerne seedlings in a greenhouse environment, and found reduction in root biomass as a result of pruning. Such greenhouse information cannot really be extrapolated to field-conditions, it is therefore important to observe the pruning influence on root growth of woody perennials in the field. Based on morphometrical analysis, Singh et al. (1992) suggested root structure and spread as two important characteristics that can influence the extent of competition. Root structure refers to arrangement of roots of > 1 cm diameter and root spread denotes

distribution of <1 mm diameter roots that were exposed in an observation plane. With this background, the present study was conducted to study the changes in the structure and spread of lucerne roots as influenced by harrow usage and shoot pruning.

Materials and Methods

The study was conducted in the same experiment, and the plots had same dimensions, as mentioned in Chapter 4. The experiment with lucerne as the test species had the following treatments: (1) normally planted lucerne, (2) normally planted lucerne, (3) lucerne planted with harrow, and (4) lucerne planted with harrow. In the normally planted treatments, the woody species was grown without any harrow. In the harrow treatments, 40 sheet harrows were used on either side of the lucerne rows at 0.3 m away to a depth of 1 m, they were installed at the time of planting lucerne in 1999. Ten rows of maize were grown, at 0.75 m x 0.30 m spacing, in all the four treatments on either side of the lucerne rows. The study was continued during the off-season, i.e., when there was no main-crop, period of 1999 (for treatments 3 and 4) and 1994 (for treatments 1 and 2). Trenching method, as suggested by Bolan (1994), was used. Trenches were dug to form an observation plane, 12 m wide and 2 m deep across the lucerne rows with the plants at the centre. The walls were smoothened and sprayed with water gently so as to expose the root tips. Ranging rods were not used the root tips were mapped on a polyethylene grid sheet. The roots of different sizes were mapped with different colours; those diameter classes of roots were mapped in the study

(1) small (<2 mm), (2) medium (2 mm to 3 mm), and (3) large (>3 mm). If a root with root hairs was protruding outside the wall, it was counted as one root even the root hairs were lying outside the observation plane (Van Nieuwenhuij, 1953). Once the root tips were stopped character-wise, the structural roots were completely exposed by spraying water. The exposed structural root system of the observed plants was then stopped in the grid sheet and the maps were captured in graph sheets; later, the graph sheets were scanned and the maps were drawn in the computer using Freehand software. Because of the enormous amount of labor involved, the observations were not replicated, hence, the information was not statistically analyzed.

Results

Root Spread

Leucaena tree grown with barrier had 33 roots (<2 mm in diameter) per 100 cm² which was four times as that of the *Leucaena* planted without barrier (Table 1-3). The hedge grown with barrier and the normally grown trees had similar root spread up to 2 m from the *Leucaena* row; but, beyond 2 m, the latter had more roots. The difference between the hedge treatments was clear as the hedge grown with barrier had approximately 7 roots per 100 cm², which was seven fold higher compared to those of normally planted hedge. While comparing the trees with hedges, the trees had two- to ten-fold higher root spread at various distances away from the tree. Highest root

Table 3: Root number distributions of lacunae in various treatments in the bread making

Distance away from the reference pole (m)				
10	天龍星南星	天龍星南星	天龍星南星	天龍星南星
20	天龍星南星	天龍星南星	天龍星南星	天龍星南星
30	天龍星南星	天龍星南星	天龍星南星	天龍星南星
40	天龍星南星	天龍星南星	天龍星南星	天龍星南星
50	天龍星南星	天龍星南星	天龍星南星	天龍星南星
60	天龍星南星	天龍星南星	天龍星南星	天龍星南星
70	天龍星南星	天龍星南星	天龍星南星	天龍星南星
80	天龍星南星	天龍星南星	天龍星南星	天龍星南星
90	天龍星南星	天龍星南星	天龍星南星	天龍星南星
100	天龍星南星	天龍星南星	天龍星南星	天龍星南星
110	天龍星南星	天龍星南星	天龍星南星	天龍星南星
120	天龍星南星	天龍星南星	天龍星南星	天龍星南星
130	天龍星南星	天龍星南星	天龍星南星	天龍星南星
140	天龍星南星	天龍星南星	天龍星南星	天龍星南星
150	天龍星南星	天龍星南星	天龍星南星	天龍星南星
160	天龍星南星	天龍星南星	天龍星南星	天龍星南星
170	天龍星南星	天龍星南星	天龍星南星	天龍星南星
180	天龍星南星	天龍星南星	天龍星南星	天龍星南星
190	天龍星南星	天龍星南星	天龍星南星	天龍星南星
200	天龍星南星	天龍星南星	天龍星南星	天龍星南星

spread was observed near the lucasins rows in all tested treatments, the highest root spread of hedges at any distance from the lucasins row was less than that of trees observed at the farthest distance. In all treatments, the top 50 cm layer had higher roots compared to lower depths. As the distance from the tree increased, however, the spread was almost uniform in all the layers. With regard to the lateral distance from the lucasins rows, root spread declined drastically beyond 2.5 m in almost all treatments especially in the barrier-used treatments.

Root structure

The barrier lucasins had longer and thicker structural roots compared to the normally planted lucasins (Fig. 2-1 and 2-2). Lucasins grown with barrier had roots of >3 cm diameter and deeply spread roots compared to lucasins planted without barrier. And, the normally planted tree had many <3 cm roots compared to the barrier-used tree (Fig. 2-3). Among the treatments, normally grown hedge had smaller (<3 cm) and shallower roots (Fig. 2-4). In both barrier-used treatments, the tree pushed the thickest spreaded and profused roots in the middle layer (Plains 1 and 2).

Discussion

The barrier used lucasins had high root spread and deeply spread structural roots. The barrier might have restricted the root growth of lucasins pushing the roots to grow in other direction. Once the roots were in the deeper layers, the structural root

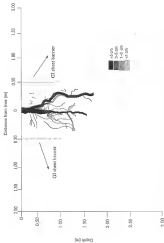


Fig. 1 Root distribution of a four-year-old tree near tree grown with barrier in the natural highlands of Kenya

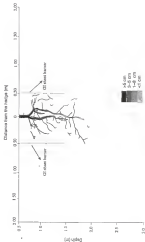


Fig. 5.2. Root structure of a four-year-old *Luxaria* hedge given with barrier in the specified height of barrier

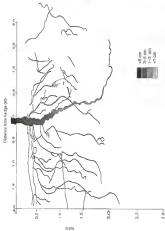


Fig. 3. Flood structure of a four-year-old *Lucania* tree (green vertical lines) in the central Highlands of Kenya.

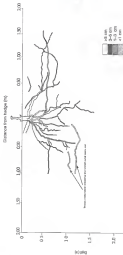


Fig 3.4. Spatial distribution of a 4-year-old osprey's rookery (green) in the northern highlands of Kenya.

might have produced high number of roots to utilize the soil resources. Although the deeper soil layers had more soil water as mentioned in Chapter 4, most of the essential nutrients are available only in the top layers. Hence the structural roots moved upward profusely, more roots in the top layer compared to the deep layers. Increased root production in the top layer could have been because of presence of oxygen and nutrients in the top layers at the onset of the growth since generally inputs $33 \mu\text{g O}_2 \text{ m}^{-2} \text{ sec}^{-1}$ as suggested by Hyn and Thaler (1977) and (Pelloni et al. (1979). It seems that the thickness of the structural roots also had a major influence on root spread since the structural-root thickness was higher in the barrier used treatments compared to the normally planted treatments. As a result of increased root spread, the extent of competition in the barrier used treatments could have been higher than or similar to that of the ones grown without barrier. Similar observations were made by Singh et al. (1989) in the natural alfalfa area in India.

Root spread and structural root spread were relatively low in the hedge treatments compared to the respective row treatments. The periodically pruned hedges became photosynthetically less active as noted by Eklund et al. (1982) in *Glomira agrostis* under subnormal N-fix conditions in Nigeria. Immediately after pruning, response demands of roots might not have been met which might have led to root death and poorer root growth in the hedges compared to the rows. It is important to note that soil water availability could have an important bearing on controlling root growth. Nevertheless, the study shows that (1) using a barrier will not inhibit root production

of the canopy species and hence below-ground competition, and (2) shoot pruning could be a useful practice in reducing stem growth of tree species

CHAPTER 3 SYNTHESIS, SUMMARY, AND CONCLUSIONS

This set of experiments was undertaken based on the previous (Chapter 2) that the most obvious effect of below-ground interactions between the hedgerow and the crop species in the natural alleyspraying system is competition for water and that the study of root dynamics is an important aspect of management of soil-water relations and, therefore, below-ground interactions. That soil water was the most important factor affecting the performance of wheat in hedgerow alleyspraying was supported by the observation that fertilizer applications did not increase wheat yields (Chapter 2) indicating that soil fertility was not a serious constraint to crop growth. Results of the hedgerow alleyspraying experiment reported in Chapter 2 showed that soil water was depleted faster in hedgerow alleyspraying system than under wheat sole-cropping. The hedgerow that had been pruned three weeks before sowing the crop had already developed an actively-leaching rhizome by the time the crop was sown, resulting in an active water uptake by the hedge and increasing water availability to the emerging crop. Apparently, in response to the water stress, the crop developed a larger root system as indicated by higher wheat root density under alleyspraying than sole cropping. As a consequence of the combined total root activity of hedgerow + wheat, the available soil water was rapidly used up, leading to rather acute water shortage in

the hedgerow intercropping system as the cropping season progressed. Under such situations, shortages of additional water through seasonal rainfall will undoubtedly result in crop failure. A feasible management strategy to minimize water demand of the hedge species, and thus increase water availability to crop, seems to be to delay the pruning of the hedgerow species in a week or two after the crop is sown. However, other field-management considerations may pose serious limitations to this option.

The effect of shoot pruning on root activity and water utilization by the woody species was investigated in the following selective experiment (Chapter 4).

Throughout the study period, soil water status in the sprayed-tree treatment was lower than in the hedgerow treatment. Therefore, the crop grown with the sprayed tree was always at a disadvantage compared to that intercropped with the hedgerow. Shoot pruning of trees not only reduced the extent of its actively transpiring root lengths (and standing in roots), but also reduced its root activity, and therefore, its vigor for below-ground competition. Thus, shoot pruning appears to be an effective management option to minimize below-ground competition.

Other than shoot pruning, management systems such as using a barrier strip around the tree was not effective in restricting the root activity of the woody species. Indeed, the root activity of the barrier-located hedges was similar to that of sprayed trees (Chapter 5), showing the ineffectiveness of such root-barrier devices in reducing below-ground competition between the tree (hedge) and the crop. The intensive and labor-intensive root-system characterization of grafted and sprayed locusts—despite the observational non-replicated nature of the study—provided insights into the existing

patterns of the species under these conditions. Furthermore, it strengthened the earlier result that shoot pruning would be an effective means of preventing root proliferation of the species.

Comparison of root turnover of *Intacta* with those of *callicarpa*, a perennial hedgerow intercropping species for additional highlands, showed that the two species were similar in their root-system behavior. Although the studies were not as detailed as on *Intacta*, these similarities suggest that the response of *callicarpa* to root management could also be similar to that of *Intacta*. Obviously this is an area that needs further investigations.

Net root contribution to soil during the crop growing season through root turnover of the woody species is an often postulated advantage of the hedgerow intercropping system. The present study does not support this view. The estimated nutrient turnover through root in root cropping season of about 130 days in the hedgerow intercropping system was 7 kg N and 0.3 kg P ha⁻¹, which are not substantial amounts by any standards. However, these results cannot be taken as fully convincing because the extent of root turnover that happens during the cropping period may not have been properly estimated by the methods used in the study.

In addition to providing new insights into the above-mentioned aspects of below ground interaction in mixed silvopasture systems (Fig. 6.1), the investigations have

UNANSWERED QUESTIONS

Are the patterns of root water depletion

either overlapping and

subsequently different?

What form of competition is more

serious

above-ground (light)?

below-ground (water, nutrients)?

What are the effects of hydroponics on

root dynamics of trees and vast

wood?

How do hydroponic roots respond to

management options such as

• shoot pruning?

• planting methods?

• spacing?

What other forms of interaction?

e.g. substrate texture by

independent roots

PROPOSED RESEARCH

Below-ground interactions

at the tree-ecoprene interface

(in the hydroponics of trees)

TREE 'WATER' DEPLETION

• Soil-water depletion is faster

under silvopasture

• Competition for light means no bare

soils around afforestation

compensate for water

efficiency: root dynamics controlled

by stress, but stress produces more

roots when water was limiting

(in silvopasture)

• Stock grazing reduces root density at

boundaries

• Laminate a more competitive (both

width) than silvopasture

• Using a barrier 1 m away from

boundaries were often not reduced

root spread

• However, silvopasture through hydroponics

root dynamics is not preferred

CONCLUSIONS

• Root systems above and underground respond to stress conditions imposed by lack of water and

pressure to other (interacting) root systems

• Stock grazing could be an effective way to manage competition, it not only reduces competition for light,

but also reduces root density at the ground surface

Fig 1.1 Summary of the results obtained from the set of studies conducted at the tree-ecoprene interface

brought into focus, perhaps for the first time, the methodological problems as well as difficulties involved in below-ground interaction studies of herbaceous+woody plant associations. Root-system monitoring will be an important aspect of agroforestry research in the future; methodological procedures for such studies will need to be standardized for general use and refined for specific systems and biotopes.

Based on the results and experience of these investigations, a few areas of future research that need serious consideration can be identified:

1. Timing of legume pruning in relation to cropping, season and its impact on root dynamics of legume species.
2. Precise estimation of nutrient contribution through root turnover in relation to legume pruning schedule.
3. Root system dynamics of commonly used legume species (other than lucerne).
4. Effectiveness of root-system investigations in host+crop relations.
5. Soil-water-depletion-patterns under legume intercropping in varying rainfall conditions.
6. Water-uptake patterns by the woody and crop components at various critical growth stages of the host crop.
7. Phytoreactive partitioning of the herbaceous species under stress environments and legume intercropping.

APPENDIX I

ROOT DISEASE OF *LEUCAEUM LEUCOCEPHALUM* AND *CALLANDRA CALATYCTANT* IN A HEDGEROW INTERCROPPING SYSTEM IN THE SUBHUMID HIGHLANDS OF KENYA

Introduction

During the early 1980s, when research on hedgerow intercropping began, it was hypothesized that incorporating N-fixing woody species in crop production fields could improve soil fertility and crop yield on a sustainable basis. The suggested management system was to grow the hedgerow shrubs and add the pruned material into the intercropping between hedgerows or alleys where food crops would be grown (Giang et al., 1981). *Leucaena leucocephala* (Lam. du Roi, Benth.) Benth. ex Mill. was selected as an inoculant was promoted as one of the best-of-not-the-best-tree for this type of food-use system because of its high foliage nutrient content, and its ability to withstand frequent pruning (Gemechar, 1987). In addition, because of the high protein foliage, *Leucaena* was widely considered as an excellent fodder species (Coffman et al., 1982). As a result, most of the hedgerow intercropping investigations in both humid and seasonal tropics were conducted with *Leucaena* as the hedgerow species. *Leucaena* is common as the hedgerow species was more often cultured in the humid tropics compared to the

seasonal crops where the species was seldom reported to be successful at such systems (Singh et al., 1988; Rao et al., 1991).

Although *Leucaena* had the ability to improve soil fertility, it was found to be a strong competitor with the crops, for resources such as water and nutrients. For example, in a study conducted comparing *Leucaena* with *Gliricidia sepium* and *Sesuvium* as hedge species in the semi-arid highlands of Kenya, Rao et al. (1990) identified *Leucaena* as the major competing species. In addition, *Leucaena* was highly susceptible to the attack of a pest, *pyralis ntereopylea cubana*, and there were incidents of the pest outbreak in epidemic proportions in many parts of the tropics during the early 1990s (ICRAF, 1993). Because of these, there were serious concerns in the popularity of *Leucaena*. Attention was therefore focused on other species with desirable attributes such as N_2 -fixation, high nutrient content of ground materials (both for green manure and fodder), and ability to withstand frequent pruning. *Calliandra calothyrsus* Willd., (hereafter referred to as calliandra) was identified as one such hedge species (Adyanapong and Munaga, 1996; Eupena et al., 1994). However, its potential as a species for hedgerow intercropping has not been fully evaluated. Compared to *Leucaena*, this species was reported to have relatively poor nutrient-releasing pattern from its foliage when used as a green manure (Mandapane et al., 1996; Mahapatra, 1992), that may lead to reduced nutrient supply to the crop when the species is used in intercropping system. With this background, a study was conducted with the objectives of: (i) comparing the root growth of *Leucaena* and calliandra, (ii) assessing the superiority of incorporating the ground materials of the hedge species on

the extent of insecticide use, and (ii) studying the performance of insecticide (organic- and culture-based) indigenous intercropping compared to sole cropping in the subhumid highlands of Kenya.

Materials and Methods

The Site

The study site is located at 0° 30' S and 37° 47' E at an altitude of 1400 m above sea level with a gentle slope of 0.5%. The average annual rainfall of about 1200 mm is received in two distinct rainy seasons, long rains (March to July; 44.5 mm) and short rains (October to February; 480 mm). Soil is deep and classified as *typic palesthumic*. The climatic data are presented in Fig. 1.

Experimental Details

The study was conducted, during the long and short rains of 1993 and 1994 as part of a collaborative research experiment of the International Centre for Research in Agroforestry (ICRAF) and Kenya Forestry Research Institute (KEFRI) at Naivasha (ICRAF, 1990). During the study period, the short rains were much below the normal, and consisted of just a few showers during the first two months. The experiment that had been initiated during the long rains of 1993 with leucaena and calliandra as the indigenous species and maize (*Zea mays* L., Hybrid 511) as the crop species was as a randomized complete block design with four replications, and the following treatments,

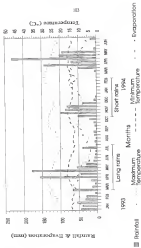


Fig. 1. Meteorological information of the study site during the long- and short-rains of 1990

- (1) hedge-row intercropping with collards as the hedge species, the hedge being pruned and the pruned materials added in situ,
- (2) hedge-row intercropping with lucerne as the hedge species, the hedge being pruned and the materials added in situ,
- (3) hedge-row intercropping with collards as the hedge species but the pruned materials removed from the plot,
- (4) sole-crop of maize with pruned materials of collards from treatment (2) added to the plot,
- (5) hedge-row intercropping with lucerne as the hedge species but the pruned materials exported to treatment (3),
- (6) sole maize with pruned materials from (5), and
- (7) sole maize grown without any pruned material or fertilizer added.

The hedges were pruned once in a season prior to the onset of the season at 2.5 m height. The plot size was 4 m x 30 m, the hedge-row intercropping treatments had two rows of woody species, spaced 4.5 m apart and 0.5 m within rows. The rows of maize were grown between the hedgerows at 0.25 m between rows and 0.25 m within each row, similar six rows as the sole maize treatments were considered for comparison.

Root samples were collected in both seasons using the coring method, as described in Chapter 3, twice during the long rains of 2010, 30 and 80 DAD, during the short rains (when the maize had failed), samples were collected only once, 70 DAD. In hedge-row intercropping plots, root samples were collected at two spots: 0.75 m away from the hedgerow, and in the middle of the alley (2.25 m away from the hedgerow).

Root samples were collected at each spot during the first sampling of long-term studies of 1993 when the maize plants were very young, and six samples were taken at 30 DAS. The samples were collected at the depth intervals of 0 to 15, 15 to 30, 30 to 50, 50 to 75, 75 to 100, and 100 to 125-cm. Four subsamples were taken for each depth within a plot. In the sole maize treatments, root samples were collected from three random spots, or both seasons, at the same depth intervals as in *Intergrow* intercropping. Root data presented here are only of fine roots (< 2 mm in diameter). Root data were log-transformed ($\log(x+1)$) and the analyses of variance were conducted. The significance of the results were based on the transformed data.

Maize grain yield, adjusted to 14% water content, was expressed row-by-row in the intercropped treatments. The crop performance at each row in *Intergrow* intercropping was compared with that of sole maize plots. *Leucaena* and *Calliandra* biomass (grassy material) was recorded and expressed as fresh weight basis for both seasons.

Results

Root density

Maize

During the long rains of 1993, 50-day-old maize in the control (sole maize) plots had relatively low root density compared to all other treatments (Table 1). Spot-wise total root density of maize in sole maize plot was 9.13 cm cm^{-2} which was 30%

Table 1. Root density of native foraging, the long rains of 1997 at 10 DMS (Days After Raining) in various treatments in the adjacent highlands of Malawi

Depth Interval	Calliandra	Leucaena	Calliandra	Leucaena	Soil Moisture	Soil Moisture
0-10	(+)	(+)	(+)	(+)	(Mean)	(Mean)
0-10	0.009	0.009	0.009	0.009	0.009	0.009
10-20	0.009	0.009	0.009	0.009	0.009	0.009
20-30	0.009	0.009	0.009	0.009	0.009	0.009
30-40	0.009	0.009	0.009	0.009	0.009	0.009

Table 2. Root density of native foraging, the long rains of 1997 at 10 DMS (Days After Raining) in various treatments in the adjacent highlands of Malawi

Depth Interval (m)	Calliandra	Leucaena	Calliandra	Leucaena	Soil Moisture	Soil Moisture
0-10	(+)	(+)	(+)	(+)	(Mean)	(Mean)
0-10	0.009	0.009	0.009	0.009	0.009	0.009
10-20	0.009	0.009	0.009	0.009	0.009	0.009
20-30	0.009	0.009	0.009	0.009	0.009	0.009
30-40	0.009	0.009	0.009	0.009	0.009	0.009
40-50	0.009	0.009	0.009	0.009	0.009	0.009

- Calliandra (+)
- Leucaena (+)
- Calliandra (+)
- Leucaena (+)
- Soil moisture
- Soil moisture
- Soil moisture

of that observed in the calliandra hedgepole intercropping (with ground material) long-term treatment. At 80 DAB, root density in the control sole maize plot was approximately 0.15 cm cm² which was 40% lower than the hedgepole intercropping plots. Root densities were similar among the hedgepole intercropping treatments and were higher in the top 0 to 10.5 cm interval in all treatments with ground material with increase in depth. At 80 DAB, however, root density in the sole maize plots started decreasing in the top soil layer; almost all other plots maintained the root density in the top layer (Table 3).

During the short rains of 1993, maize root density was higher in the calliandra plots, both in the "calliandra intercropping" and the "green manure-of-calliandra applied" sole maize plots, compared to the other treatments (Table 3). Root density declined progressively from the top layer to the lower depth intervals.

Comparing the seasons, maize grown during the short rains of 1993 had only 0.08 cm cm² which was 50% of the 1993-long-rains crop. During both seasons, root densities were similar at 0-75 cm from the hedgepole and in the middle of the alley (Fig. 1, 3, 4). Again, at both seasons, the root density during the long rains was higher than that during the short rains.

Edaphic quality

In both seasons, calliandra at 0.75 m from the hedgepole under previous "unimproved" and "improved" treatments had similar soil density at 20 and 80 DAB compared to the lucerne treatments (Fig. 2, 3, 4). Among the calliandra plots,

Table 1. Root density of maize during the first years of 1993 at 70 DAS (Days After Sowing) in various treatments in the cultivated fields of Bagan.

Depth interval (cm)	Callisaya (+)	Lucuma (+)	Callisaya (-)	Lucuma (-)	Soil Moist ¹	Soil Moist ²	Soil Moist ³
0-10	0.167	0.106	0.100	0.104	0.178	0.148	0.182
11-20	0.110	0.046	0.143	0.104	0.108	0.129	0.085
21-30	0.076	0.002	0.100	0.041	0.170	0.110	0.080
30-40	0.090	0.031	0.051	0.107	0.136	0.100	0.070
40-50	0.040	0.028	0.048	0.083	0.090	0.040	0.040
100-120	0.001	0.011	0.070	0.001	0.007	0.000	0.000
Callisaya (+)	-B1 (Callisaya with pread material incorporated)						
Lucuma (+)	-B1 (Lucuma with pread material incorporated)						
Callisaya (-)	-B1 (Callisaya with pread material treated to 100 mm ²)						
Lucuma (-)	-B1 (Lucuma with pread material treated to 100 mm ²)						
Soil moist ¹	-Soil moist given with pread material from Callisaya (+)						
Soil moist ²	-Soil moist given with pread material from Lucuma (-)						
Soil moist ³	-Soil moist given without any input						

Table 4. Predicted levels from the analysis of variance of root density at onset and the probability levels of the factors during the long and short runs of 1973

Source	Long runs				Short runs	
	50 DAS		80 DAS		Woody sp	Isolated
	Woody sp	High w	Woody sp	Isolated		
(i) Redgum monocropping						
Treatment	0.070	0.000	0.071	0.000	0.0001	0.0001
Distance	0.001	0.147	0.000	0.001	0.0005	0.100
Depth	0.000	0.000	0.000	0.000	0.0001	0.0001
(ii) young redgum monocrop						
Treatment	0.000		0.000		0.0001	
Depth	0.001		0.001		0.0001	

§ In the longrun monocropping studies, only monocropped stands root density statistics were generated

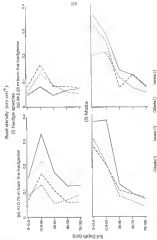


Fig. 3. Root density of the herbicide species and intercropped maize at 50 DAA during the long runs of 1993

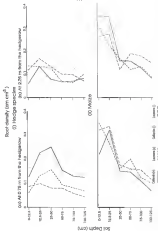


Fig. 2. Root density of the hedge species and intercropped maize at (a) 0 m, (b) 2.25 m, (c) 4.5 m and (d) 6.75 m from the hedge row during the long rains of 1993.

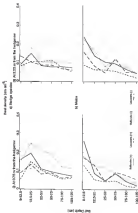


Fig. 4. Diurnal dynamics of the benthic species and biomass of *Nereis* (ind) and *Corophium* (mg) during the study period (March–November).

root density of intercropped plot was higher compared to that of the sorghum plot during the long rains as it is away from the hedgerow, however, the reverse was true during the short rains when the impact faded. In the middle of the alley, the collardale plots had almost similar root density as of close to the hedgerow, however, the locustana grown plots had higher or similar root density compared to the collardale ones. In all the hedgerow intercropping plots, both woody species, showed higher root density within 11.5 to 25 cm-depth interval compared to the control.

Yield

Maize/beans

Total yield showed that the hedgerow intercropping treatments yielded better than the control with maize especially when the pruned materials were incorporated (Table 2). Among the intercropped plots, collardale- and locustana-grown treatments (with pruned materials incorporated) yielded 2828 and 2484 kg/ha² which was approximately 45% higher than the "pruned material-exported" plots. While comparing the sole maize plot which received the pruned materials alone, the collardale-applied plot was not statistically different from the locustana-applied treatment.

During the long rains of 1993, row-by-row maize yield comparison in the collardale-grown plots showed that the middle two rows generally yielded lower compared to the outer rows although all rows yielded similarly to the locustana plots from which the prunings had been removed (Fig. 2). The row-wise yield among the

Table 8 Maize grain yield during the long runs of 1993 and biomass production of the hedge system during the long and short seasons of 1993

Treatments [†]	Maize yield (kg ha ⁻¹)	Biomass yield of the hedge system (fresh weight, t ha ⁻¹)	
	Long runs	Long runs	Short runs
Calancho (+)	2626	17.4	7.1
Leucaena (+)	2404	19.0	8.1
Calancho (-)	1831	14.7	6.3
Leucaena (-)	1612	15.3	10.4
Sole maize [‡]	1445	—	—
Sole maize [‡]	1419	—	—
Sole maize	1558	—	—
LSD _{0.05}	104	4.3	3.8

[†] The treatments are same as listed in Table 1.4

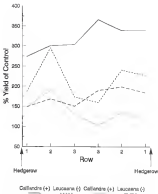


Fig. 8. Maize yield at different rows away from the hedgerow in the intercropping treatments during the long rains of 1969.

Callandria grown plots showed that the grass-applied treatment yielded 3- to 5-fold higher than the one from which grassings had been removed.

Incense-growth

A year after planting, the hedgerows were grazed for the first time two weeks before the long rains. The pruned materials from the hedgerows were, therefore, of one season. Incense production of both species was not markedly different (Table 2). Within species, however, incense and *Callandria* grown without pruned materials being incorporated produced smaller amount of incense as that of the incorporated ones. And, similar trend followed in the short rains. Generally, in both species, incense production was higher when the pruned materials were applied or removed from the system.

Discussion

During the long rains, maize root density was high in the intercropped treatments compared to the sole maize, and this was proportional to the respective above-ground biomass yields and the grain yield in the intercropped plots. Although all treatments received similar rainfall, maize grown in the hedgerow treatments performed well probably because of the complementary effects of the woody species on the crops. Evidently, maize root density in the intercropped plots was higher than that of the sole

crop. In addition, the tree root systems were very young to compare and the rainy events were minimal.

During the short rain, since the season ended four weeks prior to the root sampling (Fig 1), the magnitude of root growth was considered as an index to evaluate the maize performance. The maize-root density was low, especially in the top 30-cm layer, although the tree root density assumed the same as the crop grown during the long rain. This reduction in maize-root density could be because of two reasons: (1) poor soil water status during the short rain and (2) increased efficiency of tree root systems in water uptake (Brouwer and Van Noordwijk, 1990). However, since no data were collected on these aspects, the results are inconclusive.

Regarding the root characteristics of the tree species, callundia always had higher root density compared to locusts at 0-25 cm distance from the hedgerow, the reverse was true at 2-25 cm distance. Among the callundia treatments, root density was similar in both seasons. Root densities of locusts treatment also did not differ during the long- and short-rain. These results suggest that soil moisture was not a major factor in restricting the root growth of callundia and locusts. In addition, similar root density of the woody species in both seasons, in the top 30-cm layer, demonstrates that tree root systems are not at all affected by the seasonal failure of rain. This could also mean that the tree root systems had an edge over food crop in utilizing the soil water. If the root density of the tree species is measured as an index of its competing ability, results showed that both species can compete equally when there is competition. However, although locusts had half of callundia's root density, its effect on maize

performance was similar to that of *coluboides*, this shows that *locustorum* is more competitive than *coluboides*. In support, mass root densities at the highest treatment were lower than in the other treatments. Furthermore, higher biomass production in the *locustorum* plots compared to the *coluboides* plots suggests *locustorum* is able to absorb more soil water which may result in greater competition between the two and *coluboides* may spread. Moreover, *locustorum* was detected with roots all over the study area its root system is uniform throughout the study (Fig 1, 3, 4). However, given the age of the hedge species, it is too early to draw any conclusion about the root behaviour in relation to competition, long term root system monitoring is necessary to explain the relative-competitiveness of the two species.

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BIOGRAPHICAL SKETCH

Govindaswami was born on December 23, 1917, at Sankaragoudram, Tamil Nadu, India. He completed his high school education in 1935 and completed his higher secondary education in 1938 at the Kalamys Vallyyandu Higher Secondary School, Virudhachalam, India. In 1940, he completed his university education at the Tamil Nadu Agricultural University, Coimbatore, India, and earned BS (Agriculture) and MS (Horticulture) degrees. In 1942, he was awarded an international scholarship by the Rotary International for higher studies and was admitted to the Ph.D. program in agronomy at the University of Florida in 1943. He received another international fellowship from the International Council for Research in Agronomy, Manila, Manila, and conducted his doctoral research at the center for two years (1943 and 1944).

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy



P.K. Ramachandran Pillai, Chair
Professor of Forest Resources and
Conservation

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy



R.L. Bahr
Associate Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy



R. L. Bahr
Professor of Forest Resources and
Conservation

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy



V. L. Bahr
Professor of Soil and Water Science

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy



V. L. Bahr
Professor of Soil and Water Science

This dissertation was submitted to the Graduate Faculty of the School of Forest Resources and Conservation in the College of Agriculture and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy

May, 1956



Director, School of Forest
Resources and Conservation

Dean, Graduate School